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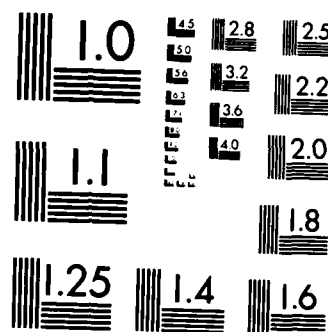
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THESIS

A SYSTEMS APPROACH TO
INVENTORY MANAGEMENT OF
REPAIRABLES IN THE NAVY

by

Chris L. Apple

March 1985

Thesis Advisor:

F. Russell Richards

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**A Systems Approach to
Inventory Management of
Repairables in the Navy**

by

Chris L. Apple
Lieutenant Commander, Supply Corps, United States Navy
B.S., Purdue University, 1970

Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

This thesis develops an inventory model for repairable items which integrates the shipboard protection level into the wholesale stock level computations. It uses mean supply response time (MSRT) as its measure of effectiveness and provides methods for computing either the required wholesale stock level given a MSRT goal or for minimizing the system MSRT subject to budgetary constraints. Examples are provided which demonstrate the benefit of not batching for repair or procurement and the benefit of reducing repair turn around times. In both instances the benefit realized is a reduction in the number of each item required at the wholesale level to achieve the desired MSRT goal.

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I. INTRODUCTION

The sophisticated weapon systems installed on Navy ships and in Navy aircraft today pose ever increasing demands on the Navy Supply System to maintain sufficient stocks of replacement components and repair parts which will ensure the desired operational readiness. The technology used in developing these weapon systems has meant a continued growth in the number of components that must be removed and returned to centralized repair facilities for repair when failures occur.

For those items designated as repairables where repair is more economical and timely than purchase, the Navy Inventory Control Points are assigned the inventory management responsibility. This thesis focuses on the inventory models used by the inventory managers at the Navy Ships Parts Control Center (SPCC) in making the repair and purchase decisions regarding repairables.

Historically, inventory models were developed for the private sector where the profit motive is paramount. Hence, most inventory models consider the various average annual variable costs associated with managing inventories and strive to minimize the sum of these costs. The relevant costs in most inventory models are order placement costs, inventory holding costs, and backorder and lost sales costs. While these types of inventory models have served the private sector well, they have less relevance to the Navy Supply System. Certainly, ordering costs, holding costs and backordering costs are important. However, it is very difficult to determine appropriate values for certain of these costs in the Defense Department. For example, a private concern might be able to estimate the cost

associated with a lost sale, be it lost profit or lost goodwill. In the Navy the cost of a stockout may be the inability of a ship to deploy on schedule or to accomplish a mission. In addition, the Defense Department is not interested in profit maximization. Instead, it is interested in having a Navy which is ready to respond to any threat. An objective which maximizes some measure of readiness is therefore appropriate.

Since the Department of Defense clearly has a different objective than does the private sector when it comes to inventory management, several inventory models have been developed over the past twenty years for the different services. But the current inventory models used by SPCC for repairables are still based primarily on cost minimization even though the Chief of Naval Operations has specified that Supply Material Availability (SMA) is to be the measure of effectiveness. SPCC attempts to resolve this dichotomy by relating SMA to a backorder cost. Rather than continuing to try to combine these two objective functions it seems logical to concentrate on the more important one. Therefore, the objective of this thesis will be to attempt to develop an inventory model for repairable items at the wholesale level which is readiness vice cost orientated.

Chapter II of this thesis presents an overview of the repairables system and the functions of the Inventory Control Points (ICPs). This discussion will demonstrate the importance that supply response time has on operational readiness.

Chapter III provides a description of the mathematical models in use today for the management of repairables and some explanation of their development.

Chapter IV discusses two of the inventory models which have been developed for other services and will point out their shortcomings for Navy use.

Level 3: all of the above and planned requirements during the repair-turn-around-time, war reserve requirements, and the demand during repair-turn-around-time;

Level 4: all of the above plus the economic repair quantity.

SPCC uses two different methods for scheduling repair actions. The first of the two methods is Workload Forecasting and Scheduling. The concept behind Workload Forecasting and Scheduling is that for certain repairable items the demand is such that there are benefits to be realized by scheduling the work well in advance of the expected demand. This concept is supported by the realization that a portion of the cost involved in repairing an item is the administrative cost of repair order preparation. Additionally, when an item is scheduled for repair in this manner the repair activity is afforded more planning time to ensure that the necessary technical documentation is available and to allow the repair activity to order and stock repair parts that have historically been required to effect the repairs.

After the quarterly levels program has been run, a tape of candidates for workloading is extracted. This is done quarterly. However, all items are not considered each quarter. In alternating quarters, items with commercial repair activities and those with organic (Navy) repair activities are selected and reviewed. For an item to be considered as a candidate it must have experienced a demand within the preceding two years. This selection criteria usually results in about half of the items in an appropriate category (organic or commercial) being selected as candidates.

The tape of candidates is then processed by the SPCC Fleet/Industrial Support Group. The resulting product is a

The probability distributions are:

MARK I AND III - Negative Binomial

MARK II and IV - Normal

MARK 0 - Poisson

The forecasting procedure used by UICP is exponential smoothing. This gives the forecast value as a convex linear combination of the last quarterly observation and the old forecast, i.e.

$$\begin{aligned} \text{New Forecast} = & \alpha * (\text{last observation}) & (\text{eqn 2.1}) \\ & + (1-\alpha) * (\text{old forecast}), \end{aligned}$$

where: $0 < \alpha < 1$.

The value chosen for the weighting factor " α " is a function of the MARK category of the particular item and also any trend that is observed. Hence, if there is an unexpected increase in demand during the most recent quarter, the weight applied might be decreased unless the previous quarter also indicated a similar increase in demand.

H. REPAIR AND PROCUREMENT ACTIONS

The purpose for all the files updating and levels computations that have been described above is to generate repair and procurement decisions. First, the quantity to be repaired is determined. Since the ICP is required to work within a budget constraint, the number of repair actions may be adjusted based on this constraint. In order to ensure that the highest priority work is accomplished when funds are limited, the ICP separates repair actions into four levels. These levels and the associated repair actions they include are:

Level 1: high priority backorders and referrals;

Level 2: all backorders, referrals, and high priority planned program requirements;

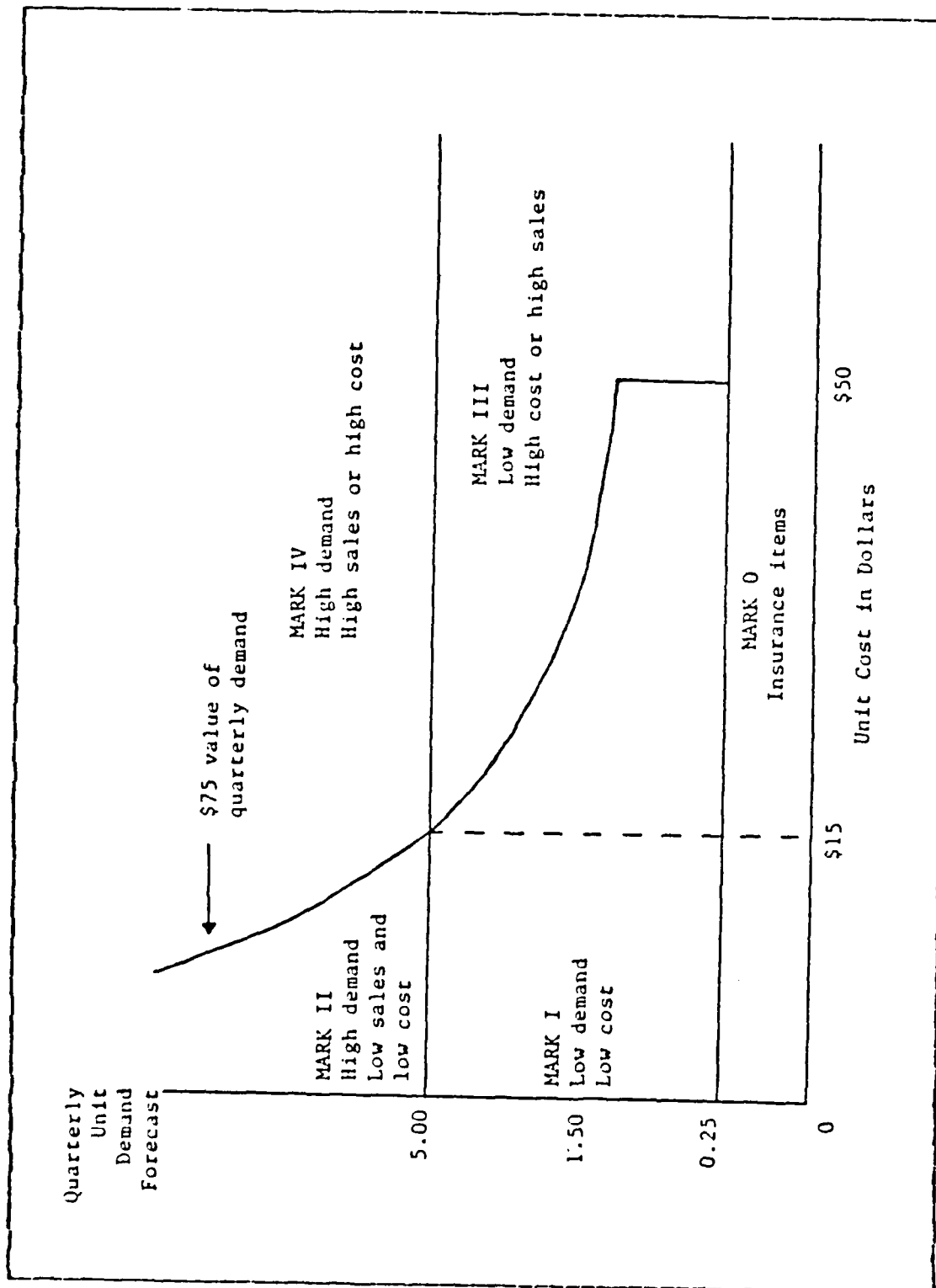


Figure 2.2 UICP MARK Codes

The inventory models reside in D01. These inventory models, like the ones in the private sector, are cost minimization models even though the goal of the Supply System is to maximize the percentage of requisitions filled from on-hand assets, called Supply Material Availability (SMA), subject to the limited budget available. Like most inventory models the costs that the UICP models consider in their calculations are ordering, holding, and stockout costs. The D01 program draws upon the MDF, IHF, and the RMF to update forecasted demands, carcass returns, repair survival rates, lead times, and repair turnaround times. Based upon the updated forecast, the D01 program computes new system reorder levels, reorder quantities, repair levels, repair quantities, and safety stock levels. The new levels are used in subsequent programs to aid the inventory manager in making the repair and procurement decisions.

G. FORECASTING PARAMETERS

As discussed above, the UICP cyclic levels and forecasting programs update the information, such as demand rate, repair time, procurement lead time, and survival rate, used in the repair and procurement models. However, all items stocked in the supply system do not experience similar demand patterns and there are vast differences in the unit prices of these items. Therefore UICP uses a breakdown of the items into groupings called MARKs. These MARK assignments are made by UICP in order to select appropriate forecasting and inventory level computation techniques. There are five MARK categories which are presented pictorially in Figure 2.2. Associated with each MARK is a set of parameters which affect the forecasting computations. Also associated with each MARK is a probability distribution which theoretically describes the demand for an item within a particular group.

capabilities. Through these reports, the UICP files are updated to reflect issues, receipts of RFI assets from repair or procurement, transfer of NRFI assets to repair facilities (most commercial repair facilities do not have TIR capabilities) and disposal of assets. B04 is the tool used by the inventory manager to update the Planned Program File and the Due-in/Due-out File. B04 also generates follow-ups on overdue receipts. Hence, the inventory manager can determine if the material has been received but not reported. This helps ensure the integrity of the data base.

Carcass tracking (B05) is the inventory managers watchdog for ensuring that failed units are returned to the supply system by the end user. Since the purpose of a repairables system is to return failed units to a RFI condition, it is imperative that the carcasses be turned in. Hence, this program monitors carcass turn-ins, and generates carcass return statistics. Since this program keys on the document number, it is essential that the turn-in document number and the requisition document number match.

Planned requirements (B02) updates the PPR files and ensures that non-recurring demands such as initial outfitting allowance increases, and planned overhauls are accounted for in forecasting future needs. Since PPRs are normally established with a specified need date, B02 helps maintain the integrity of the PPR file by generating warnings when need dates have passed and the requirement has not been removed from the PPR file.

The Cyclic Levels and Forecasting (D01) programs are the cornerstone of the UICP system. While all the other programs update files, manage data, generate reports, and initiate follow-ups, it is the D01 program that computes repair and procurement quantities. The D01 program is run quarterly and reflects the budget execution strategy of the ICP through the establishment of stocking objectives.

Hardware System Commands, or the inventory manager. Since these demands are of a non-recurring nature they are loaded into this special file to ensure that they are included in planning for future repairs or procurements.

The Due-in/Due-out file tracks the outstanding supply actions affecting wholesale system stock. This file tracks ICP directed issues and referrals, receipts from repair or procurement, and stock relocations. This file is available on a real-time basis.

The Inventory History File (IHF) is a tape file which contains recurring demands, carcass returns, assets, back-orders, lead times and turnaround times for the past eight quarters. This file is accessed by batch processing only.

F. UICP PROGRAMS

The files discussed above are used by the UICP repairables management programs. Certain of the more important programs are discussed below.

Requisition processing (B01) is the program that acts on behalf of the inventory manager when a requisition is passed to the ICP due to lack of stock at the point of entry stock point. If assets are available elsewhere the requisition is referred by B01 to a stock point holding assets. However, if there are insufficient assets, then the requisition processor will generate a Stock Status Report (SSR) which advises the inventory manager of the backorder situation. B01 also generates data used to produce a number of statistics which are provided on a daily and monthly basis to the inventory manager.

Transaction Item Reporting (B04) is the means by which the UICP files obtain most of the information concerning changes to the wholesale system assets. Most activities holding wholesale stock have daily transaction reporting

D. THE UNIFORM INVENTORY CONTROL PROGRAM (UICP)

While the inventory manager has the ultimate responsibility for managing the repairables under his cognizance, his job would be unmanageable without the aid of the Uniform Inventory Control Programs (UICP). These are the various programs that have been developed and which are maintained by the Fleet Material Support Office (FMSO) in support of the ICPS. UICP keeps track of the multitude of details about each item and provides essential management reports to aid the inventory manager.

E. UICP FILES

All the key data necessary to operate the inventory control system and UICP are maintained in the Master Data File (MDF) filed by the item's National Item Identification Number (NIIN). Each data element is uniquely identified by a Data Element Number (DEN). Each NIIN has approximately 400 such data elements which include such information as on-hand quantity, average quarterly demand, unit price, replacement price, repair cost, procurement lead time, repair lead time, noun name, dimensions, and packing and packaging information. The MDF data are accessible via real-time data retrieval.

The Repairables Management File (RMF) is a file similar to the MDF which contains organic and commercial repair performance data such as inductions, completions, and surveys. The RMF is an on-line file.

The Planned Program Requirements (PPR) file is another on-line file which contains information necessary for the proper management of repairables. A planned requirement is any known or anticipated project or program related requirements that would not otherwise be forecasted. These requirements are based on requests from field activities,

is involved in just about every phase of the repairables cycle.

The inventory manager's primary function is to ensure that all requests for material under his cognizance are satisfied in a timely manner. Hence, he will position the RFI stock at the various stock points where he expects requisitions to enter the system. If stock is not available at the point of entry stock point then the requisition is transmitted to the ICP and the inventory manager must either refer the requisition to a stock point holding assets or backorder the requisition awaiting the availability of stock.

Once the requisition has been filled, the inventory manager must ensure that the requisitioner returns the failed unit to the supply system. As stated above, this is tracked by the requisition document number. If a matching turn-in document number is not received by the inventory manager, then he must initiate follow-up actions to ensure that the carcass is returned by the end user.

To aid in communicating turn-in directions to end users, the inventory manager is responsible for keeping the information in the Master Items Repairables List current and correct. This includes the turn-in destination, method of shipment, and priority of shipment.

Two other major functions of the inventory manager are the repair and procurement decisions. Tools to aid him in these decisions are discussed below. However, the ultimate responsibility for ensuring that failed units are repaired in a timely manner and for ensuring that additional units are procured when the quantity being provided through repair is inadequate to satisfy demands is that of the inventory manager.

the same document number on the turn-in document as was used on the requisition. The shipboard supply personnel will consult the Master Item Repairables List (MIRL) to determine the shipping address for the failed unit. This could be either a Navy Supply Center or the actual repair facility depending on the essentiality of the item. Certain items which must be returned quickly to an RFI condition are under special management programs and will not be discussed further.

Assuming the failed unit is shipped to a stock point, it will be held there until a predetermined quantity have accumulated at which time the carcasses are transferred to a repair facility. The repair facility could be either Navy (organic) or commercial. Once the repairs are complete, the item is sent to a Navy stock point where it is placed into stock awaiting issue to satisfy an end user requisition. If the item is needed immediately it may be shipped directly from the repair facility to an end user.

The amount of time it takes for an item to complete the repairable cycle can be very important to the operational readiness of a ship. The cycle as depicted in Figure 2.1 assumes that stock is available at the stock point to issue immediately to satisfy a requisition. However, this is not always the case. As a result, the replacement of a failed unit may be delayed due to the replacement item still being in repair or in transit from the repair activity to the stock point.

C. THE INVENTORY CONTROL POINT

As stated above, the ICP (SPCC) is at the hub of the repairables cycle. Inventory managers are key personnel at the ICP. Each inventory manager is assigned many repairables for which he is responsible. In carrying out his duties he

end of 1984, repairable items accounted for over 73 percent on this investment (approximately \$4.9 billion). However, these same items represent only about 17 percent (88,000 of the 518,000) of the total items managed.

B. SYSTEM OVERVIEW

The previous section explained why an item is designated as a repairable and described the different maintenance levels. However, repairable item inventory management at the Inventory Control Point (ICP) considers only those repairable items which are repaired at a DOP. This section provides a discussion that repairables "cycle".

Figure 2.1 illustrates the theoretical flow of the Depot Level Repairable (DLR) as it travels through the Repair Cycle. As depicted, this is a closed loop cycle in which all failed units are eventually returned to a serviceable ready-for-issue (RFI) condition. At the hub of the repairables cycle is the ICP, which in this case, is SPCC.

The cycle starts when a shipboard installed DLR unit fails. At that time shipboard personnel determine from the technical and supply documentation available that the item is a Depot Level Repairable. If a spare DLR is authorized and available it is drawn from the ship's supply department and installed. If not, a request in the form of a requisition is submitted to the nearest supply activity for a replacement. Even if a spare is carried and installed, a replacement will be requisitioned to maintain shipboard stock. Key throughout this phase of the repairables cycle is the requisition document number which is unique for each such request.

After the failed unit (the carcass) has been removed from the parent weapon system it must be returned to the supply system. For control purposes, the end user will use

The level of repair decision subsequently impacts the supply support provided at the organizational level. If an item is deemed repairable at the organizational level the repair parts support, repair equipment and maintenance personnel must be made available at that level. However, if the item is not repairable at that level, then the question is whether the item can be replaced by the organizational level. If so, then spare modules should be carried at the organizational level.

Organizational level repairables will normally be transferred to the next higher echelon of repair if the repairs cannot be accomplished at the organizational level. The same is true for the intermediate level maintenance repair actions.

Repair parts support for a repairable designated for intermediate or depot level repair is not as clearly defined as it is for the organizational level. These upper echelons of repair are not provided with allowance lists of repair parts in support of items they are required to repair. Also, repair parts needed to support repair actions at the intermediate or depot level sometimes are not identified or stocked when the component or module is not designated as repairable at the organizational level.

Both repair costs and repair time must be considered in making the decision to repair an item. Even though the repair cost often amounts to less than half the item replacement cost, what is often even more significant is the time involved. Whereas most failed repairable units can be returned to "ready for issue" condition in 90 to 180 days, the procurement of these same items could easily take more than two years if a replacement can be procured at all. Therefore, repairables management has become an essential part of the Navy Supply System. Specifically, of the over \$6.6 billion in Supply System assets managed by S²CC at the

II. REPAIRABLES AND THE NAVY SUPPLY SYSTEM

A. REPAIRABLES-DEFINATION AND DETERMINATION

An item of supply is designated as a repairable if it can be repaired faster and less expensively than it can be procured. Repairable items include such items as pumps, motors, circuit boards, amplifiers, power supplies, and test equipment.

Weapon systems installed in ships and aircraft have become increasingly sophisticated and complex. Hence, many weapon systems are made up of a number of subsystems which in turn are comprised of several replaceable modules. Often the complexity of these individual modules is such that the personnel and equipment are not available at the end use level to repair failed units. Consequently, these modules are designated as repairables and failed units are returned to designated repair activities or Designated Overhaul Points (DOP) for repair.

The decision as to whether an item of supply will be a consumable or repairable is made during the Weapons System Acquisition process. This is the period during which the system is designed, maintenance requirements determined, supply support established, and the system procured and installed. Also, during this phase, decisions are made concerning which maintenance levels will repair the failed item. The levels under consideration are: (1) the lowest level (such as the ship), called the organizational level; (2) the intermediate level such as a Tender or a shore Intermediate Maintenance Activity; or (3) the depot level such as a Navy Shipyard, Industrial Naval Air Rework Facility or a commercial repair activity.

Chapter V presents the development of a proposed model for the ICPs which uses minimization of Mean Supply Response Time as its objective.

Chapter VI provides examples using the model developed in Chapter V. Based on these examples, Chapters VI and VII present final results and conclusions regarding the proposed model.

workload forecast schedule which is reviewed by the cognizant inventory managers. Finally, the Fleet/Industrial Support Group meets with the various repair activities and a workload schedule is agreed upon for the subsequent six month period. Only about a third of the original list of candidates get workloaded. The major problem with this evolution is the fact that an item which is a workload candidate is not considered by the second repair scheduling program during the workload scheduling preparation time period. The files for those items that are workloaded are updated to reflect the scheduled due-ins from repair.

The second method of repair scheduling is the use of the UICP B08 program. This program is run monthly. It looks at all items that have not been designated as workload items. Just like the Workload Forecasting Program, B08 uses the levels that were set during the most recent levels setting update, and the scheduling is done according to the Urgency of Need Level which helps to ensure that repair dollars are spent on the most critical repair actions. The time horizon of B08 is repair turn-around time.

After the B08 program is run and the recommended repair actions are provided, the inventory manager must then ensure that each of the items is scheduled for repair. This entails the preparation of contracts or work orders for each of the items. Hence, there is usually more administrative lead time involved in the repair process for items recommended for repair via B08 than there is for workloaded items.

Both of the repair scheduling procedures described above function under the assumption that there will be sufficient NFRI carcasses available in the system to support the repair actions. This assumption is not always valid, and, as a result, the inventory manager occasionally finds himself in a carcass-constrained situation where repair actions have been recommended but carcasses are not available on which to perform the repair.

The third and final method of increasing the number of ready-for-issue assets is through procurement. Recommended actions concerning procurement are also accomplished via the UICP programs. This program, known as the Supply Demand Review (SDR), is designed to be run daily. However, SDR is not run daily for repairables. Instead, it is usually run bi-weekly or monthly depending on availability of procurement funds and computer time.

The Supply Demand Review program is run independently of both of the repair scheduling programs. It functions under the assumption that the planned repair quantities will indeed be repaired.

SDR makes buy recommendations to the inventory manager. For any procurement action to take place the inventory manager must act on these recommendations. If the buy quantity is approved, then the procurement process is initiated. This entails a considerable amount of administrative time for the preparation of procurement technical packages and the placement of contracts. The SDR programs do include a fixed amount of administrative lead time but, if the actual time is greater than the lead time allowed by the inventory model, the inventory manager may discover that the system runs out of stock prior to the delivery of assets from procurement.

I. REPAIRABLES FUNDING

Before discussing repairables funding it is necessary to understand the distinction between the two types of repairables carried in the Navy Supply System. The first type, called principal items are repairables which include major assemblies such as aircraft engines, complete radar sets, gun mounts, and etc. These items are funded by Appropriation Procurement Accounts. The other type, called secondary

items, are replacement assemblies and smaller components. Repairables of this type, which are managed by SPCC, were transferred to the Navy Stock Fund (NSF) for funding purposes on 1 April 1981.

The Navy Stock Fund is a revolving fund managed by NAVSUP. As a revolving fund, the NSF consists of money and/or stock. When stock is issued, the stock fund is reimbursed by the customer, and these resources are used to purchase new items or to repair NRFI items to replace the inventory that has been issued. Hence, when a ship requisitions a SPCC managed DLR, the ship pays for the item from its operating funds. However, since the carcass will be repaired the requisitioner does not pay the full purchase price of the DLR. Instead, the price is approximately 25-30 percent of the replacement price of the DLR. This price is based on the expected repair cost, the replacement cost of items that are beyond economic repair, and the NSF surcharge. If the requisitioner does not turn in the NRFI carcass for repair, then the total replacement price of the item is charged against the ship's operating funds. This method of charging for DLRs has significantly improved the turn-in rate of failed carcasses for repair.

III. THE UICP INVENTORY MODELS

A mathematical model is a simplified representation of a real world problem, situation, or system. Mathematical models are developed in an effort to determine an optimal solution for the problem it represents. Often real world problems are so complex that even after the simplifying assumptions used in developing the mathematical model, analytic solutions are not possible. In such instances, optimal solutions may only be approximated. As will be seen below, the UICP models use approximations along with additional simplifying assumptions to arrive at solutions to the inventory problem.

In the area of inventory models, most models have been developed based on either a concept of maximizing a business profit where a company such as a department store sells retail goods or minimizing costs where a company keeps stocks of raw materials on hand to use in a manufacturing process. In either context the desire is to minimize the costs associated with carrying inventory while ensuring that enough stock is maintained to satisfy demands.

A. THE SPCC REPAIRABLES MODELS

The SPCC inventory models for repairables are not nearly as simple as the basic inventory models which assume constant continuous demands. Many of the other assumptions are the same, but the SPCC repairables models do recognize the fact that some of the factors affecting the cost function are random variables. The basic goal of the SPCC repairables model is to minimize the expected annual variable costs of operating the wholesale supply system. Again the

costs involved are the ordering costs, holding costs, and shortages costs. The ordering costs are the ICP internal administrative costs of placing orders and the manufacture's costs to set-up a production or repair line. The holding costs are those costs associated with maintaining on hand inventories - storage, obsolescence and opportunity cost. The shortage costs are those costs representing the cost to the system of incurring backorders.

The SPCC repairables models for computing procurement and repair quantities currently perform these computations independently. However, SPCC is in the process of implementing an integrated repairables model.

These models assume a continuous demand distribution with a constant mean and standard deviation. Also the models assume a continual review of assets versus requirements. These assumptions are depicted graphically in Figure 3.1. (Figure 3.1 shows the demand as being constant at its mean value but that is only to simplify the illustration.)

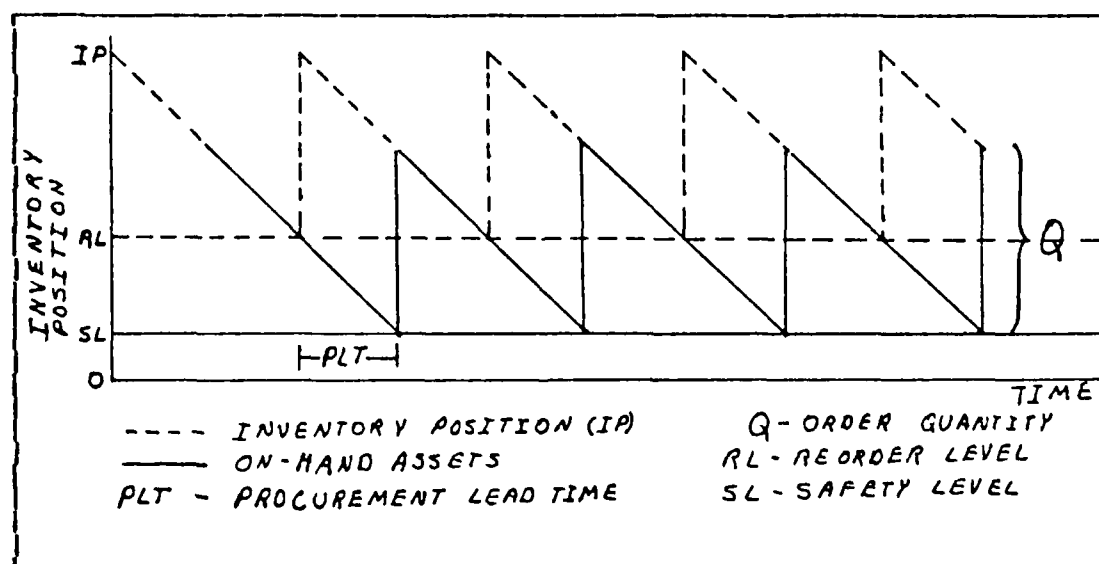


Figure 3.1 SPCC Inventory Model

Notice that the SPCC repairables model keys on inventory position (IP) for the asset picture which is composed of: on-hand RFI assets plus assets due-in from procurement or repair plus on-hand NRFI assets factored for survival rate less due-outs to satisfy backorders and due-outs from referrals.

Under the assumptions of this model, buy or repair orders are generated whenever the IP reaches the reorder level (RL). Since demand is in discrete units vice continuous and since the review of the asset position is not continuous this model violates the assumptions necessary for an optimal solution.

Before describing the SPCC model it is important to understand the measures of effectiveness used by the Navy Supply System. While costs are very important to the Navy and these models attempt to minimize cost, cost is not, in fact, the ICP's measure of effectiveness. The goal of the Navy is to keep ships operational and, to accomplish this goal, requests for material must be satisfied. Hence, the Navy uses Supply Material Availability (SMA) as its measure of effectiveness. SMA is the percentage of requisitions filled by the system without delay for those items which are carried in stock. However, SMA is not included in the reorder/repair computations. Instead, a variable called RISK is used. RISK is defined as the probability of running out of stock in an order cycle. There is no simple relationship between RISK and SMA but they are linked by the shortage cost used in the inventory models. RISK is used in computing the safety level and hence the reorder level, whereas SMA considers both the order quantity and the safety stock. These two measures are often confused and mistakenly used interchangeably, but it is important to realize that they are different and that RISK is the variable used in the SPCC inventory models.

B. THE PROCUREMENT MODEL

As described in Inventory Management [Ref. 1: Ch. 3 App. A], the SPCC repairables procurement model starts with a total variable cost (TVC) equation which is minimized:

$$\begin{aligned} \text{TVC} = & \hspace{15em} (\text{eqn 3.1}) \\ & ((\text{expected no. of orders per year}) * (\text{cost per order})) \\ & + ((\text{cost to hold one unit per year}) \\ & * (\text{aver. no. of units on hand})) \\ & + (\text{shortage cost}) \end{aligned}$$

where shortage cost, is determined by a requisitions short model.

$$\begin{aligned} \text{Shortage costs} = & (\text{cost per requisition backordered}) * \\ & (\text{expected no. of order cycles per} \\ & \text{year}) * \\ & (\text{expected no. of requisitions backorder} \\ & \text{per order cycle}) \end{aligned}$$

This TVC equation is symbolized by:

$$\begin{aligned} \text{TVC} = & (((4 * (D - G)) / Q) * (A)) + ((I * C) * ((Q / 2) + \hspace{1em} (\text{eqn 3.2}) \\ & R - (D * L) + (G * L) - (G * T) + B1)) \\ & + (((\lambda_1 * E) * ((4 * (D - G)) / Q) * (B2)) \end{aligned}$$

where: D: mean quarterly recurring demand forecast;
G: mean quarterly repair regeneration forecast;
4*(D-G): mean annual attrition recurring demand forecast;
Q: order quantity;
A: internal ICP cost of placing an order plus the manufacturer's setup cost;
I: inventory holding rate; composed of storage, obsolescence, and opportunity cost rates;

C: unit cost;

L: mean procurement lead time forecast;

T: mean repair cycle time;

λ_1 : shortage cost per requisition short;

E: military essentiality weight;

B1: ICP approximation to the average number of backorders at any point in time:
 $\int_0^{\infty} (x-R) f(x;L) dx$;

B2: ICP approximation to the expected number of requisitions backorder in an order cycle:
 $(F/D) * \int_R^{\infty} (x-R) * f(x;L) dx$;

F: mean quarterly requisition frequency forecast;

R: reorder level;

D/F: average requisition size;

$f(x;L)$: probability distribution of lead time demand.

The calculus is used to minimize the TVC equation with respect to order quantity (Q) and reorder level (R). When the first partial derivatives with respect to Q and R are set equal to zero, the resulting formulas for determining Q and R are:

$$Q = ((8 * (D-G)) / (I * C))^{1/2} * (A + (\lambda_1 E * (F/D)) * \int_R^{\infty} (x-R) * f(x;L) dx)^{1/2}, \quad (\text{eqn 3.3})$$

and

$$\text{RISK} = \int_R^{\infty} f(x;L) dx = (Q * I * C * D) / ((Q * I * C * D) + (4 * \lambda_1 * E * F * (D-G))). \quad (\text{eqn 3.4})$$

Note that Q and R are related and independent solutions are not possible. Also observe that the expression $\int_R^{\infty} f(x;L)dx$ is the complementary cumulative distribution for demand during lead time x . If the lead time demand were distributed according the Normal distribution then the lead time demand could be represented pictorially as shown in Figure 3.2 .

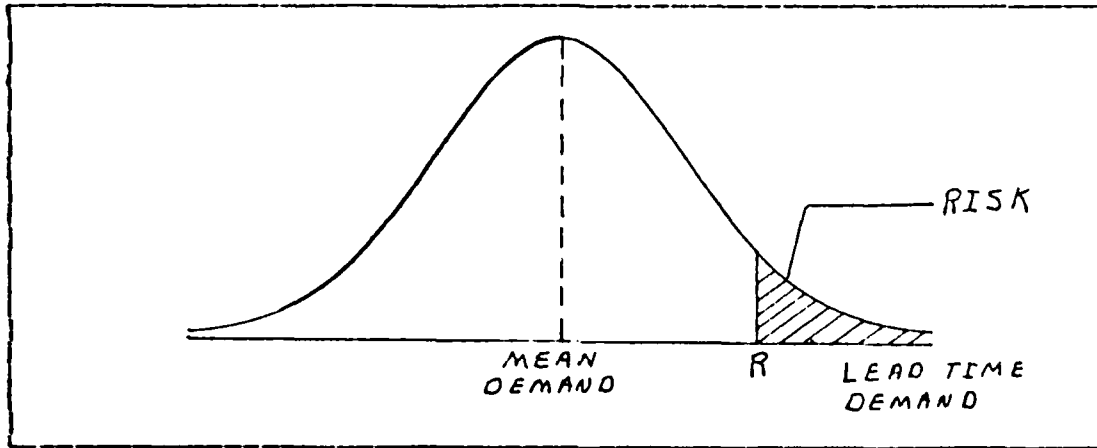


Figure 3.2 Lead Time Demand

The shaded area under the Normal curve in Figure 3.2 represents the probability of demand exceeding the reorder point in an order cycle, this is the quantity defined as RISK. Equation 3.3 cannot be solved independently for Q , therefore, UICF uses the Wilson EOQ formula as an approximate solution for Q :

$$Q_W = ((8 * (D - G) * A) / (I * C))^{1/2}. \quad (\text{eqn 3.5})$$

This value for Q is then used in the RISK equation to generate the reorder level (R).

To ensure that the Wilson EOQ approximation for the order quantity is not so large that it could result in stock

becoming obsolete, or so small that more than one order would need to be placed in a quarter (perhaps creating an excessive procurement workload), constraints are imposed on the order quantity. The order quantity constraints attempt to limit the order quantity to no less than some percentage of quarterly attrition demand $(D-G)$, not more than 3 years worth of attrition demand and not less than one unit or 3 months worth of attrition demand.

$$Q^* = \min \begin{cases} 12*(D-G) \\ \max(K0*(D-G), 1, Qw) \end{cases}$$

where: if $(D-G) \leq 0$, Q is set to 1,

if $K0=0$, $K0$ is set to 1.

$K0$ is an ICP input parameter which is set equal to 1, 2, 3, or 4 to ensure a minimum order of at least 3, 6, 9, or 12 months attrition demand respectively. Additional constraints are imposed if the item is a shelf life item or if a life of type (LCT) quantity has already been procured.

The UICP model also constraints the risk value to be no smaller than a minimum specified value, ρ_s , and no larger than a maximum value, ρ_L . The right hand side of equation 3.4 is then computed using Q^* . If we denote the result as Ω , then the constrained procurement stockout risk is taken to be:

$$\rho_i = \min(\rho_L, \max(\rho_s, \Omega)).$$

After the acceptable procurement stockout risk, ρ_i , is determined, the reorder level is computed. The reorder level depends on the expected value and standard deviation of attrition demand during the order cycle. UICP identifies the expected attrition demand as the Procurement Problem Variable (Z) where,

$$Z = (D*L) - (L*G) + (T*G). \quad (\text{eqn 3.6})$$

If Z is greater than or equal to a predetermined input parameter the attrition demand is assumed to be normally distributed. If the item is MARK 0, then the attrition demand is assumed to be Poisson. Otherwise the demand is assumed to be distributed according to a negative binomial distribution.

For the normal distribution the reorder level (R) is computed as follows:

$$R = Z + z * \sigma, \quad (\text{eqn 3.7})$$

where: σ : standard deviation of attrition demand;

z : standard normal deviate for a complementary cumulative probability equal to ρ_i .

For the negative binomial let $p(x;L)$ be the probability of exactly x attrition demands in a lead time. Then R is determined to be the smallest integer such that:

$$\sum_0^R p(x;L) \geq (1 - \rho_i). \quad (\text{eqn 3.8})$$

Since the negative binomial distribution is a discrete distribution, the above inequality is computed recursively until the value of R is determined.

In addition to the limits on RISK, the reorder level is bounded above and below according to other ICP established constraints.

C. THE REPAIR MODEL

The SPCC repair model also starts with a total variable cost equation [Ref. 1 : Ch. 3 App. A]. The repair model, like the procurement model, uses a requisitions short model in developing the TVC equation but uses a cycle time equal to the depot level repair turnaround time. The total variable cost equation for the repair model is :

$$\begin{aligned} \text{TVC} = & (((4 * \min(D, G)) / Q2) * A2) + & (\text{eqn 3.9}) \\ & (I2 * C2) * ((Q2 / 2) + (R2 - (D * T2) + B3)) \\ & + ((\lambda 2 * E) * ((4 * \min(D, G)) / Q2) * (B4)), \end{aligned}$$

where: Q2: repair quantity;

A2: administrative costs of placing a repair order plus the set up cost for the repair time;

C2: cost to repair one unit;

R2: repair level;

T2: depot level repair turnaround time;

B3: expected number of units backordered at any random point in time. It is approximated in UICP by $\int_{R2}^{\infty} (x - R2) * f(x; T2) dx$ for ease of taking derivatives;

$\lambda 2$: repair shortage cost per requisition backordered;

E: military essentiality weight;

D: mean quarterly recurring demand forecast;

B4: expected number of requisitions backordered in a depot level turnaround time (This is expressed as $(F/D) * \int_{R2}^{\infty} (x - R2) f(x; T2) dx$);

$4 * \min(D, G) / Q2$: expected number of repair orders in a year.

This model is also solved using the calculus to give:

$$Q2 = ((8 * \min(D, G)) / (I2 * C2))^{1/2} * (A2 + (\lambda^2 * E * (F/D) * \int_{R2}^{\infty} (x - R2) * f(x; T2) dx))^{1/2}, \quad (\text{eqn 3.10})$$

and

$$\int_{R2}^{\infty} f(x, T2) dx = (Q2 * I2 * D) / ((Q2 * I2 * C2 * D) + (4 * \lambda^2 * E * F * \min(D, G))). \quad (\text{eqn 3.11})$$

Like the procurement model, an approximation similar to the Wilson EOQ is used for Q2.

$$Q2 = ((8 * \min(D, G) * A2) / (I2 * C2))^{1/2}. \quad (\text{eqn 3.12})$$

And for R2 UICP uses:

$$\begin{aligned} \text{RISK} &= \int_{R2}^{\infty} f(x; T2) dx \\ &= (Q2 * I2 * C2 * D) / ((Q2 * I2 * C2 * D) + (4 * \lambda^2 * E * F * G)). \end{aligned} \quad (\text{eqn 3.13})$$

Like the procurement quantity, the repair quantity is also constrained.

$$Q2^* = \max \left\{ \begin{array}{l} 1 \\ \min \left\{ \begin{array}{l} Q2 \\ 4 * D * H - \max(0; \text{safety level}) \\ \text{LOT} - R2 \text{ if } (\text{LOT} = 0) \end{array} \right. \end{array} \right.$$

where: H: shelf life;

safety level: constrained repair level minus
the average depot turnaround time
demand ($Z2 = T2 * D$);

LOT: life of type buy quantity which is a
quantity sufficient to sustain operation of
weapon system throughout its life.

Next, the basic repair level is computed for normally distributed demand using

$$R2 = T2 * D + \text{safety level.} \quad (\text{eqn 3.14})$$

The safety level is computed using equation 3.13.

The repair level is also constrained by shelf life requirements and the number of stock points authorized to stock the item (policy receiver stock points) so that:

$$R2 = \max \left\{ \begin{array}{l} 0 \\ \min \left\{ \begin{array}{l} \max(R2, \text{no. of policy receivers}) \\ 4 * D * H + Z2 - 1 \end{array} \right. \end{array} \right.$$

Note: if D, G, or Z2 = 0, then R2 = Z2.

D. INTEGRATED REPAIRABLES MODEL

As stated earlier, the requirements computed by the procurement and repair models are accomplished independently of each other. This has resulted in situations where the computed procurement inventory level for an item did not provide sufficient carcasses to allow repairs at the computed repair inventory level.

As stated in [Ref. 1] NAVSUP has made some changes in the models described above in an attempt to integrate the calculation of the safety levels, reorder levels, and repair level. These changes should minimize the occurrence of carcass shortages. The integrated repair model has only a single RISK equation

$$\text{RISK} = (I * C3 * D) / ((I * C3 * D) + (\lambda * F * E)), \quad (\text{eqn 3.15})$$

$$\text{where: } C3 = (G/D) * C2 + (1 - (G/D)) * C.$$

The new procurement reorder level and repair level are computed as follows:

$$R = Z + \text{safety level;}$$

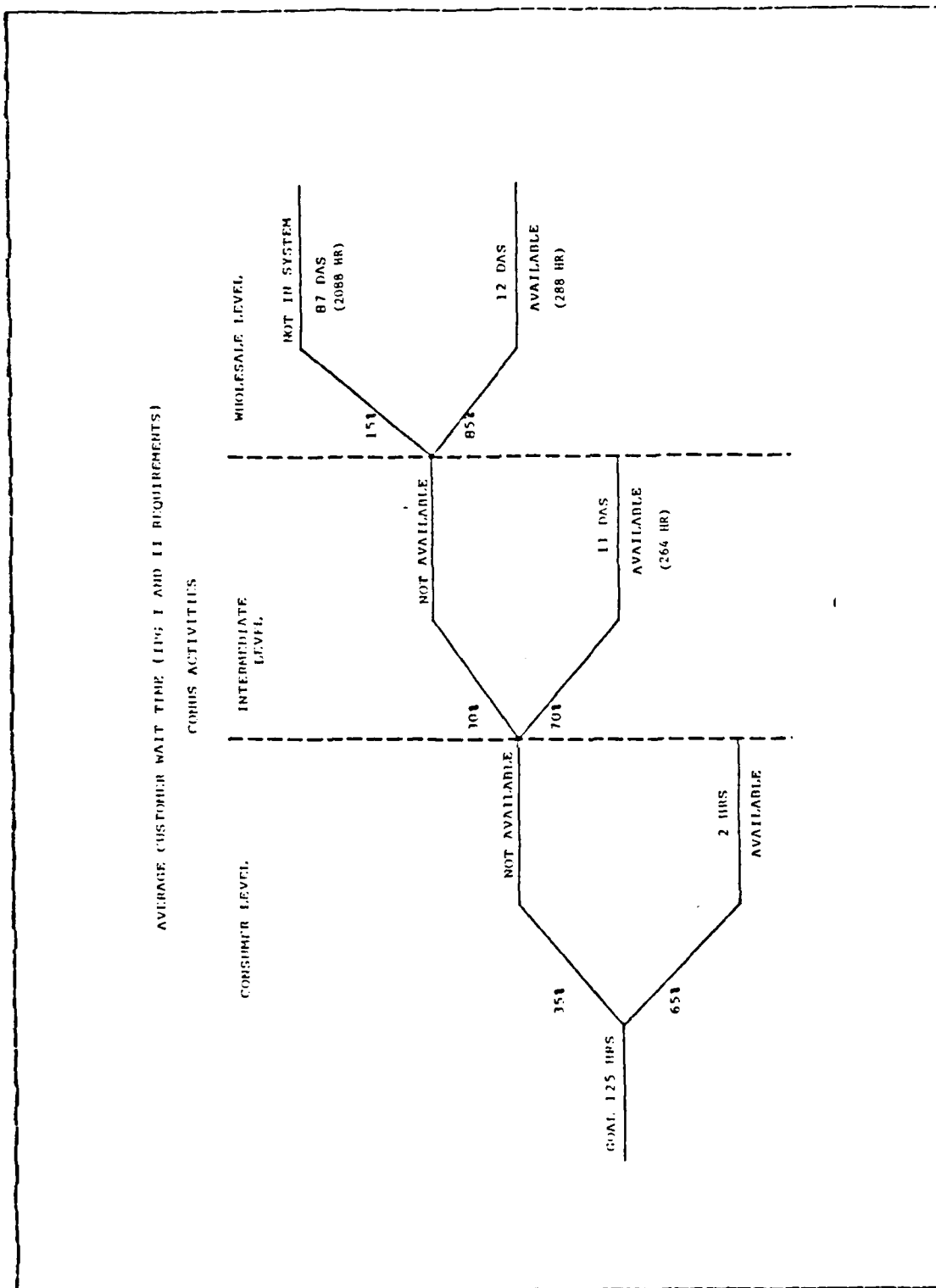


Figure 5.4 MSRT Goal in CONUS

is not to minimize MSRT. Instead, it is to determine that quantity of stock required by the wholesale system which will ensure that the supply system meets a specified MSRT goal.

As discussed in [Ref. 1: Ch. 4] the MSRT goal for the Navy supply system for immediate use requirements (Issue Priority Group I and II) is 125 hours for ships in CCNUS and 135 hours for ships EXCONUS. Obviously, this goal cannot normally be met by the wholesale system. Realizing this, the Navy has specified goals for each echelon of supply. The goals are depicted in Figures 5.4 and 5.5 .

The model which we develop does not consider an intermediate level of supply. Consequently, we will focus on the requirements at the wholesale level.

G. THE STOCHASTIC REPAIRABLES CYCLE

Thus far we have only considered a deterministic model for the repairables cycle. But this is not realistic. In fact, all times under consideration are actually random variables as is the time between failures. Hence, in this section we account for these stochastic elements.

In addition to the above assumptions concerning demand and the times considered, the following assumptions apply to the model being developed here:

- (1) failures are generated by a Poisson process;
- (2) ships use a one-for-one reorder policy for stock authorized on board;
- (3) the minimum protection level of spares is the same for all ships;
- (4) DOPs are established for all items;
- (5) attrition of items, due to not being turned in or being beyond economic repair, is allowed;
- (6) repair batch size and procurement lot size are

E. BATCHING REPAIRS AND PROCUREMENTS

In the previous examples the difference in the quantity of wholesale stock that must be maintained to support the repairables cycle when batching is imposed indicates that there is a cost associated with batching repairs. In this case the cost is R-1 additional units of stock. So batching should be avoided unless there are other economic considerations or unless the DOP specifies the batch size. These examples also illustrate that the economic repair quantity (ERQ) is unity if the objective is to minimize supply response time.

If we assume that a certain percentage of the failed units are either never returned to the supply system or not economically repairable, then the same argument that was made concerning batching for repair can be made for procuring attrited units. Namely, the optimal (with respect to supply response time) procurement quantity is $Q=1$. If the system is forced to delay procurement until Q units have been attrited then an additional quantity of stock must be held in inventory to account for the queueing of the attrited units for procurement. Therefore, unless economic reasons dictate, such as order preparation cost or quantity discounts, the supply system should follow a one-for-one ordering policy for stock lost through attrition.

F. MEAN SUPPLY RESPONSE TIME - THE OBJECTIVE

Mean Supply Response Time (MSRT) is the mean time it takes the supply system to respond to the demand for a replacement part or component. Hence, MSRT is a better indicator of how well the supply system supports ship requirements than other measures of effectiveness such as supply material availability. Therefore, MSRT was chosen as the measure of effectiveness for this model. However, the goal

In the example in Figure 5.2 let $T_1=0.5$, $T_2=0.25$, $T_3=0.25$, $RTAT=1.0$ and $\Delta T=0.5$. SW is computed to be 4.

Next, as is often the case with repairables, assume batching of the quantity to be repaired. This simply means that a quantity of R carcasses must be available at the NSC before they are inducted into the DOP for repair. The formula for SW in this case is given by equation 5.2.

$$SW = (T_1 + T_2 + T_3 + RTAT + ((R-1) * \Delta T)) / \Delta T. \quad (\text{eqn 5.2})$$

If $R=3$ for the data of the above example, the situation is illustrated in Figure 5.3. The resulting solution from equation 5.2 is $SW=6$ for the same set of parameters.

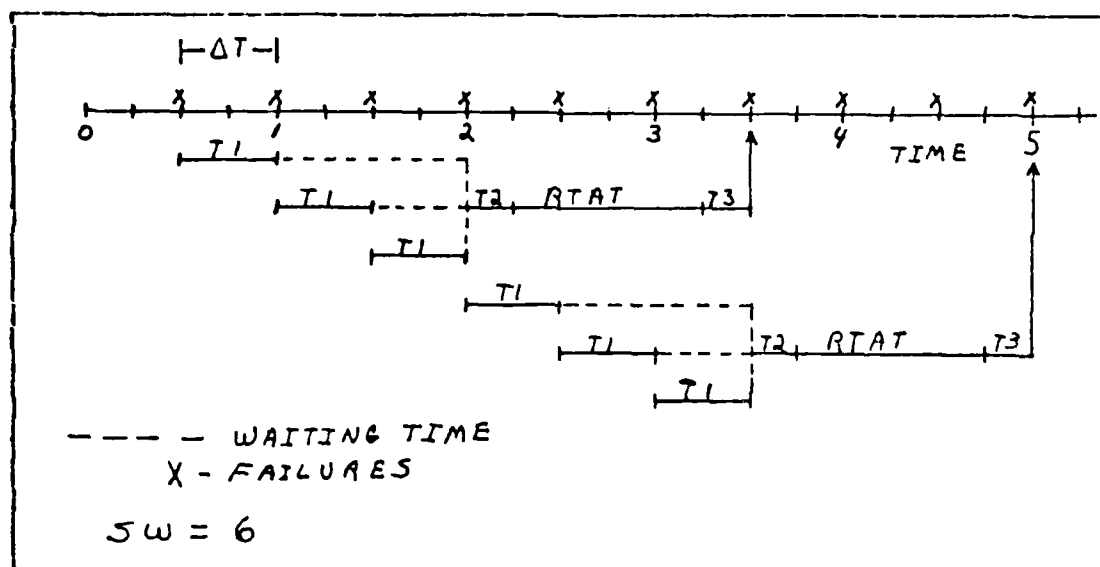


Figure 5.3 Deterministic Model with Batching.

The term $(R-1) * \Delta T$ that appears in equation 5.2 accounts for the added delay required to accumulate the necessary R carcasses at the NSC prior to beginning repair.

shipboard level. Hence, all demands for material must be satisfied from the wholesale level. Finally, we assume several ships with like units installed constitute the fleet to be supported. The objective is to determine the level of stock that must be maintained in the wholesale system, SW , so that the only delay experienced at the shipboard level is the shipping time of an RFI unit from the NSC to the ship.

For this model there must be enough stock at the NSC when the cycle starts to satisfy all demands until the first unit that failed is back at the NSC in RFI condition and available to satisfy the next demand. This model is depicted graphically in Figure 5.2. The solution for this simple model is:

$$SW = (T_1 + T_2 + T_3 + RTAT) / \Delta T, \quad (\text{eqn 5.1})$$

where: SW : wholesale stock level (RFI and NRFI);
 ΔT : mean time between failures.

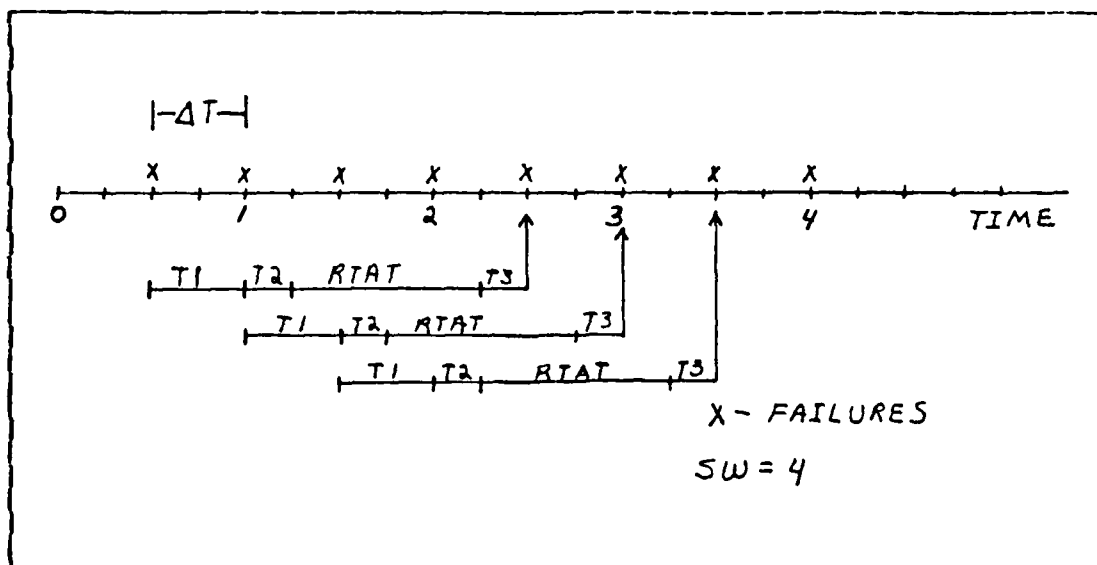


Figure 5.2 Deterministic Model With No Batching.

In this simplified version there are various times depicted which represent the average times it takes for a certain event to occur.

- T1: carcass turn-in time; i.e. the time it takes for a carcass to be received at the collection point (NSC) after a demand has been registered (this includes shipboard turn-in time and shipping time);
- T2: shipping time for a carcass from the NSC to the designated overhaul point (DOP);
- T3: shipping time for an RFI unit from the DOP or a manufacturer to the NSC;
- T4: shipping time for an RFI unit from the NSC to a ship;
- T5: time required for the ICP to determine that a carcass will not be returned to the system;
- RTAT: time required for the DOP to repair an item or a repair batch and return it/them to RFI condition;
- ALT: administrative lead time required by the ICP to prepare a purchase order or contract and the ordering data to purchase a replacement item;
- PLT: production lead time required by the manufacturer to manufacture the quantity of an item being purchased.

The times used throughout will be the average times expressed in quarters.

D. A DETERMINISTIC MODEL

Let us first consider a model in which all times are assumed constant and known and demands are assumed to be deterministic, one demand every ΔT units of time. We assumed there is no batching for repair nor attrition of failed units (i.e. all failed units are returned to an RFI condition). Assume also that no stock is carried at the

provided at the shipboard level, there still exists the need for replenishment when a spare is issued from shipboard stocks.

The model described below will take the support provided at the shipboard level into consideration when determining the wholesale system stock level. While this is not a multi-echelon model in the sense that it does not determine stocking objectives for the ship, it does identify instances where the mean supply response time goal is not obtainable because the shipboard protection level is inadequate.

C. THE SYSTEM

The entire repairable cycle was described in Chapter II, however, for convenience, a simplified representation is provided in Figure 5.1.

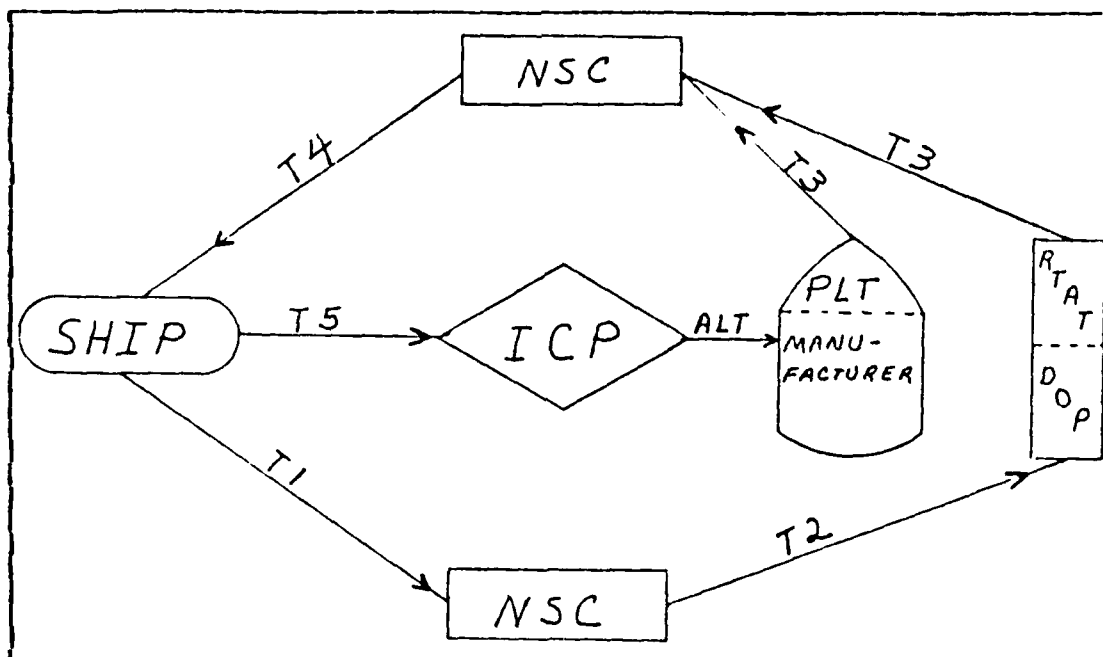


Figure 5.1 Repairables Cycle.

V. MEAN SUPPLY RESPONSE TIME REPAIRABLES MODEL

A. INTRODUCTION

Thus far we have described the repairables cycle, the goals of the Inventory Control Point, the inventory manager's functions along with the tools at his disposal, and the mathematical models that have been developed to aid the inventory manager in making repair and/or purchase decisions. Also, we have provided two examples of inventory models that have been developed specifically for military supply systems.

The inventory management of repairables in the Navy is a difficult problem which is receiving a lot of attention. As is evident from the development of the integrated repairables model and Fleet Material Support Office study of existing multi-echelon models [Ref. 2], the Navy is looking for ways to improve supply support of repairables while staying within the limits of a budget constraint. This chapter provides the development of a repairables inventory model at the wholesale level which focuses on Mean Supply Response Time while including the protection level specified at the shipboard level as an input parameter.

B. PROBLEM STATEMENT

Because of the need to repair weapon systems when ships are deployed, Navy ships do maintain stocks of spare parts and components on board. However, due to space limitations, lack of repair capability, or equipment at the shipboard level, or just due to very low expected failures, not all system components are supported. Hence, support often reverts to the wholesale system. Even if spares support is

- (5) repair depots return repaired items to central supply stock points;
- (6) repairable items may be condemned at the depot level resulting in the need to procure replacements;
- (7) procurements at the wholesale level follow a one-for-one policy so there are no economies of scale (no economic order quantities are computed);
- (8) repair capacity is assumed unlimited and items are not batched for repair.

As stated above, ACIM attempts to maximize the operational availability of a weapon system. This is accomplished by determining the stocking objectives for each level in the supply hierarchy which either minimizes the mean supply response time or which satisfies a specified goal. The solution is computed within the context of a budget constraint.

ACIM, as in the case of METRIC, uses marginal analysis and Lagrangian techniques to derive an optimal solution. While this is possible, it must be recognized that the computational complexity of this problem is immense for a weapon system with several levels of indenture and a large number of parts where the supply system has several echelons. Despite the possible computational difficulties associated with ACIM, FMSO in [Ref. 2] states that "Based on the documentation analysis performed in this study (FMSO Report 160) there is no reason to prefer any other requirements determination model over ACIM". This, coupled with the fact that ACIM has already been approved for use in determining end use stockage quantities for selected equipments, makes it a model that the Navy considers will help the supply system support the specified operational readiness requirements.

$$A_o = (\text{up time}) / (\text{up time} + \text{down time})$$

$$= \text{MTBF} / (\text{MTBF} + \text{MTTR} + \text{MSRT}),$$

where: MTBF: mean time between failures;

MTTR: mean time to repair;

MSRT: mean supply response time.

The goal of ACIM is to maximize the operational availability (A_o) of a weapon system subject to a given inventory budget. Hence, the objective of ACIM is to determine stock levels for all repair parts in the equipment such that the MSRT is minimized subject to given constraints. ACIM assumes that the MTBF and MTTR are independent of the stockage policy and are given constants.

Another feature realized by the ACIM model is that various indenture levels exist in a weapon system. Hence, if repair parts support is provided at the end use level for a repairable module then there may not be a need to provide a spare module. Hence, ACIM attempts to specify the optimal mix of spare consumable parts and repairable components which will achieve a specified level of operational readiness for a weapon system within the inventory budget constraints.

ACIM incorporates many of the same assumptions that are applicable to METRIC, but there are some additional ones. The assumptions as stated in [Ref. 4] for the ACIM model are:

- (1) all stockage locations use a continuous review and one-for-one (S-1,S) ordering policy;
- (2) demands at the wholesale level are stationary and compound Poisson distributed;
- (3) repair times and shipping times are constant and known;
- (4) lateral resupply at a particular echelon is not allowed (e.g. no ship-to-ship resupply);

stations implying that there are always ample servers at the repair facility.

As stated above, METRIC was one of the first readiness oriented inventory models. METRIC attempts to minimize total base backorder delay subject to an investment constraint. METRIC computes both the optimal stock level at each of the J bases and at the depot for each of I items. The methods used to compute these optimal quantities are very time consuming and are considered to be computationally infeasible for stocking a large number of items over several bases.

The Fleet Material Support Office reviewed METRIC and concluded that METRIC would not suit the needs of the Navy. Their objections to METRIC as stated in [Ref. 2] are:

- (1) METRIC is a base/depot model which is strictly aircraft oriented and which does not represent the Navy Supply System.
- (2) METRIC does not allow for procurement since attrition is assumed to be zero.

C. AVAILABILITY CENTERED INVENTORY MODEL (ACIM)

One of the first multi-echelon inventory models developed specifically for the Navy was the Availability Centered Inventory Model (ACIM). ACIM was developed in 1981 by CACI, Inc. and approved by the Chief of Naval Operations for use in determining consumer level stockage quantities for selected equipments.

ACIM recognizes that the purpose of a supply system is to provide sufficient support so that a weapon system is operational when it is needed. The terminology used to describe this goal is operational availability (Ao). Specifically, as described in [Ref. 4],

Control (METRIC). METRIC was developed by Rand Corporation in 1966 for the Air Force. METRIC is described in detail in [Ref. 3] and a summary is provided in [Ref. 2]. A brief summary of METRIC is provided here.

METRIC is applicable to a two-echelon system and assumes that there are a total of I items in the entire system. Since this is a repairables model, each of these items can be returned to an RFI condition after failure occurs. There is one central repair facility or depot that is capable of repairing any of the different items. Additionally, there are J bases that stock some or all of the different items. Each of the bases is capable of performing some repairs on failed units, but due to limited capabilities some failed items must be returned to the depot for repair.

METRIC assumes that failures of item i at base j follow a compound Poisson process. The probability that a failed unit of item i can be repaired at base j is $r(ij)$. Hence, with probability $(1-r(ij))$, item i will be transferred by base j to the depot for repair. When an item is transferred to the depot for repair a replacement is ordered from the depot to replenish base stock, hence, a one-for-one $(S-1, S)$ stocking policy exists. Since failures are assumed to be generated by a compound Poisson process, it follows that the demands registered at the depot from each base for an item are also compound Poisson distributed. Finally, the sum of demands at the depot from all bases for item i is a compound Poisson process.

METRIC further assumes that the expected repair time of item i at base j is $A(ij)$; the expected ordering and shipping time for item i to base j is $O(ij)$; and the expected repair time of item i at the depot is $D(i)$ --all known constants. Also, METRIC assumes no attrition (all failed units are repairable) and no lateral resupply between bases. METRIC does not allow queueing or batching at the repair

IV. REPAIRABLES INVENTORY MODELS IN THE DOD

The Department of Defense has realized over the past twenty years that the military services need inventory models that are readiness oriented. Additionally, as stated in FMSO Report 160 [Ref. 2: p. 1] the FY78 Defense Authorization Act stipulated, "The budget for the Department of Defense submitted to Congress for FY79 and subsequent fiscal years shall include data projecting the effect of the appropriations requested for material readiness requirements". Hence, there have been several readiness oriented models developed for the military services. FMSO Report 160 [Ref. 2] provides a detailed report of most of those models and describes how they might apply to Navy applications. This chapter provides a discussion of two of those models.

A. MULTI-ECHELON INVENTORY MODELS

Along with the development of inventory models that were based on readiness was the realization that there was a need to integrate the hierarchical structure of the supply system into the decision process. Thus, in 1958 Rand Corporation developed the first "multi-echelon" inventory model for the Air Force. As a result, many of today's models which calculate stockage levels for each of the levels in the hierarchical supply system are referred to as "multi-echelon" inventory models.

B. MULTI-ECHELON TECHNIQUE FOR RECOVERABLE ITEM CONTROL (METRIC)

One of the first multi-echelon models to claim optimality was the Multi-Echelon Technique for Recoverable Item

$$R2 = D \cdot T2 + \max(0, R - Z).$$

These values are not subject to additional constraints since the equations used to compute the procurement order and repair quantities were unchanged and all previously mentioned constraints are still in effect.

E. CONCLUSIONS

The SPCC repairables models are basically cost minimization inventory models where the safety level, repair level, and procurement reorder level depend on an allowable risk of being out of stock during the repair time or procurement lead time. While these models follow the classic inventory modeling concept, they do little to capture the repairables cycle as described in Chapter II. The techniques currently used to improve SMA, the current measure of effectiveness, is to change the acceptable RISK level by altering λ , the shortage cost.

The ICP simulation programs have shown that the integrated repairables model will improve the carcass constraint situation but this is realized to be only a quick fix to a more serious problem. Specifically, the current models do not accurately represent the system as it exists.

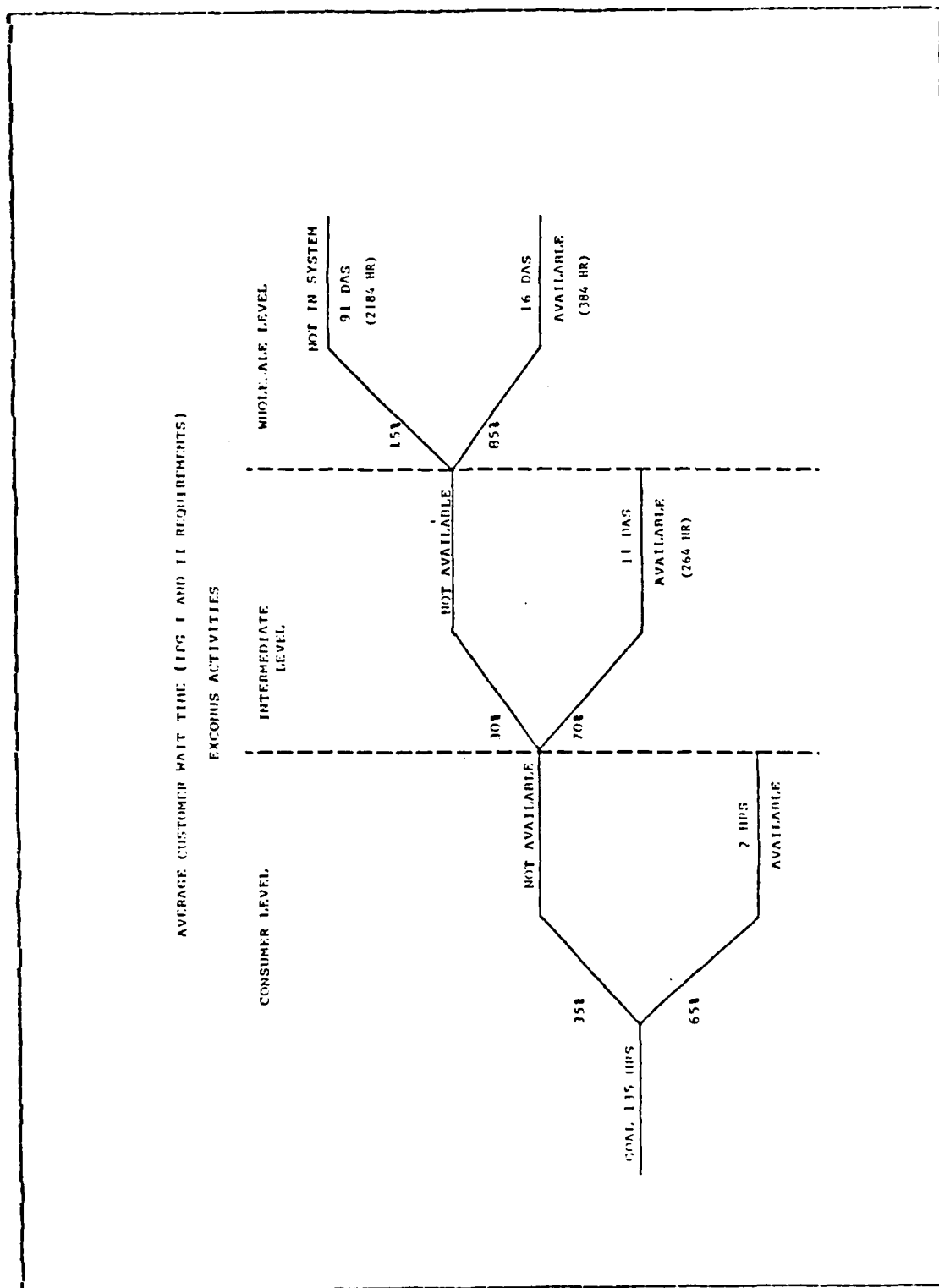


Figure 5.5 MSRT Goal EXCONUS

input parameters which are determined outside the model;

- (7) all demands for stock are satisfied by the wholesale system - no lateral resupply.

First it is appropriate to explain Palm's Theorem which will be used to derive certain results. Palm's Theorem, as explained by G.B. Crawford [Ref. 5], states that if failures or demands are Poisson distributed with rate λ and the mean resupply time is T then the mean number of items in resupply is Poisson distributed with parameter λT . Hence, this theorem allows us to determine the distribution of the number of units in resupply without knowing the distribution of the lead time random variables. All that is required is that the mean of the lead time distribution is known.

For the purposes of this model, there are two resupply routes or cycles. The first being the repair cycle and the second the procurement cycle. Since the shipping time from the NSC to the ship for an RFI unit is the same regardless of how the unit was furnished, the time (T_4) need not be considered as part of the resupply cycle.

H. THE REPAIR CYCLE

The times that affect the turnaround time in the repair cycle are T_1 , T_2 , $RTAT$, T_3 and any delay resulting from batching of repairs. The carcass turn-in time (T_1) will often depend on the availability of a spare unit at the shipboard level. Hence, if a spare is available the NRFI unit will be turned in immediately. If one is not available, the unit will often remain in place until a replacement is received from the wholesale system. Therefore:

$$T_1 = ((1-\rho) * T_{1S}) + (\rho * (T_{1S} + MSRTW)),$$

where: T_{1S} : turn-in time for a carcass from a ship to the

NSC if a spare DLR is available in shipboard stock;

MSRTW: mean supply response time at the wholesale level;

T1S+MSRTW: turn-in time for a carcass from a ship to the NSC if a spare DLR is not available in shipboard stock;

ρ : probability that a spare DLR is not available in shipboard stock.

This expression is circular in that MSRTW depends on T1 which in turn depends on the resupply time of the wholesale system. However, for carried items, it is expected that ρ is small and that the model will attempt to drive MSRTW to a value which is small compared to T1S. Consequently, T1 will be assumed constant in our model at a value equal to the shipping time from the ship to the NSC.

As shown in the deterministic models, the effect of batching for repair is to increase the length of the repair cycle and, consequently, the number of spares needed by the wholesale system. Therefore, we want to determine the average time added to the repair cycle ($W(R)$) given that the repair batch size has been predetermined to be R . Since failures which can be returned to an RFI condition occur according to a Poisson process at rate λ_r , the carcasses enter the queue awaiting repair at a rate of λ_r . The number of carcasses in the awaiting-repair queue; i.e. $(0, 1, 2, \dots, R-1)$, constitute a continuous time Markov chain (CTMC). Since the number of carcasses in the queue can only transition from 0 to 1, 1 to 2, ..., $R-2$ to $R-1$, and $R-1$ to R or 0 (since the repair batch is inducted for repair when the R th carcass arrives), the probability of transitioning from state i to state $i+1$ is one (1). This produces the embedded discrete-time Markov transition matrix:

	0	1	2	3	4	5	.	.	.	R-2	R-1
states											
0	0	1	0	0	0	0	.	.	.	0	0
1	0	0	1	0	0	0	.	.	.	0	0
.	.										.
P =	.	.									.
.	.										.
R-2	0	0	0	0	0	0	.	.	.	0	1
R-1	1	0	0	0	0	0	.	.	.	0	0

which is doubly stochastic and, as shown by Ross [Ref. 6: p.152], has a limiting probability of $1/R$. Hence, the probability of being in any state of the embedded Markov chain is uniform on the set $(0,1,2,\dots,R-1)$ with the mean being $((R-1)/2)$. Since this is a CTMC, the amount of time spent in each state before transitioning to the next state is exponentially distributed with mean $1/\lambda r$. Also the time spent in state i and state $i+1$ are independent random variables. Therefore, the average time added to the repair cycle is:

$$W(R) = (R-1)/(2 * \lambda r). \quad (\text{eqn 5.3})$$

The other times affecting the repair cycle: T_2 , $RTAT$, and T_3 , are the average observed times measured in quarters. So the mean length of the repair cycle ($TT1$) using the variables described above is:

$$TT1 = T1 + T2 + RTAT + T3 + W(R). \quad (\text{eqn 5.4})$$

I. THE PROCUREMENT CYCLE

The times that affect the mean procurement time in the procurement cycle are: T_5 , ALT , PLT , T_3 , and any delays resulting from the batching of attrited units to accumulate an economic order quantity before placing a procurement order. The delay resulting from batching for procurement is determined in the same way that the repair delay was determined. Here, the system must wait for Q attritions before procurement action is taken. Therefore,

$$W(Q) = (Q-1)/(2 * \lambda_p), \quad (\text{eqn 5.5})$$

where: Q : procurement quantity, and

λ_p : failure rate of units that must be replaced through procurement.

So the mean length of the procurement cycle (TT_2) using the variables described above is:

$$TT_2 = T_5 + ALT + PLT + T_3 + W(Q). \quad (\text{eqn 5.6})$$

J. THE TOTAL RESUPPLY CYCLE

Above we have developed the mean repair cycle time and the mean procurement cycle time. We now are in a position to develop the mean resupply time and the mean number of units in resupply.

The underlying assumption in this model is that failures follow a Poisson process. Therefore, if there are I items in the supply system and J ships, each with varying populations of the I items installed and each having an associated failure rate, then they each contribute to the demand on the wholesale system at a rate D_{ij} . As shown by Ross [Ref. 6: p. 52] the sum of Poisson random variables each with a mean D_{ij} is also a Poisson random variable with the mean equal to the sum of the individual means. Hence, for item i , $D_i = \sum_{j=1}^J D_{ij}$.

Further, if there is a probability γ_i that a failed unit can be returned to an RFI condition through repair and a probability of $(1 - \gamma_i)$ that an item must be replaced through procurement, then these two processes are independent Poisson processes with rates of $\gamma_i * D_i$ and $(1 - \gamma_i) * D_i$ respectively. (Note the $\gamma_i * D_i$ and $(1 - \gamma_i) * D_i$ replace λ_r and λ_p respectively when computing $W(R)$ and $W(Q)$ above.)

By using Palm's Theorem, as explained earlier, the number of units in the repair cycle and procurement cycle are Poisson distributed with respective parameters:

$$\mu_{ri} = \gamma_i * D_i * TT1i, \quad (\text{eqn 5.7})$$

$$\mu_{pi} = (1 - \gamma_i) * D_i * TT2i. \quad (\text{eqn 5.8})$$

And, since the number of units in the two cycles are independent Poisson random variables, the sum, which is the total number of units in the resupply cycle, is also a Poisson random variable with a mean equal to the sum of the means:

$$\mu_i = (\gamma_i * D_i * TT1i) + ((1 - \gamma_i) * D_i * TT2i) \quad (\text{eqn 5.9})$$

$$= D_i * ((\gamma_i * TT1i) + ((1 - \gamma_i) * TT2i))$$

$$= D_i * U_i.$$

where: U_i is the mean resupply cycle time for item i .

Hence, when expanded, the mean number of units of item i in resupply is:

$$\begin{aligned} \mu_i = & (\gamma_i * D_i * (T1 + T2 + RTATi + T3 + \\ & ((Ri - 1) / (2 * \gamma_i * D_i)))) \\ & + ((1 - \gamma_i) * D_i * (T5 + ALT + PLTi + T3 \\ & + ((Qi - 1) / (2 * (1 - \gamma_i) * D_i)))). \end{aligned} \quad (\text{eqn 5.10})$$

K. THE REPAIRABLES MODEL

Our objective is to find the level of wholesale stock, SW_i , (consisting of both RFI and NRFI assets) for each of the I items in the supply system required either to minimize the MSRT subject to a budget constraint or to determine the minimum cost solution which attains a predetermined MSRT goal. To do this we must find the total expected delay due to the wholesale system. The mean supply response time is obtained by dividing this total delay by the total expected number of failures. Now, it is known that the expected number of backorders at a randomly selected time is equivalent computationally to the total expected time-weighted units short (TWUS) per unit of time (see, for example [Ref. 7: p. 185.]).

Let $B(SW_i; \mu_i)$ be the expected number of backorders for item i at a randomly selected time. Then:

$$TWUS_i = B_i(SW_i; \mu_i) = \sum_{x_i = SW_i + 1}^{\infty} (x_i - SW_i) * p_i(x_i; \mu_i). \quad (\text{eqn 5.11})$$

This expression can be rewritten as:

$$TWUS_i = (\mu_i - SW_i) + \sum_{x_i = 0}^{SW_i - 1} (SW_i - x_i) * p_i(x_i; \mu_i). \quad (\text{eqn 5.12})$$

If we divide the total time weighted units short per unit time, $TWUS_i$, by the total expected failure rate, D_i , we get the average delay per failure or the mean supply response time for item i . In our model, this is the mean supply response time for the resupply cycle and will be denoted as $MSRTRS_i$. To account for the shipping time from the NSC to the ship, T_4 , we will denote the mean supply response time for the wholesale system as $MSRTW_i$ where:

$$MSRTW_i = T_4 + MSRTRS_i.$$

Previously, we defined the Navy wholesale system mean supply response time goals as 353 hours in CONUS and 382 hours EXCONUS. However, if these goals were not defined, the following method could be used to select an initial value for an MSRTW goal to be used in calculating an initial estimate of SW:

$$MSRT = (\rho * MSRTW) + ((1-\rho) * MSRTS),$$

which implies: $MSRTW = (MSRT - (1-\rho) * MSRTS) / \rho,$

where: MSRT: goal of the supply system;

MSRTS: mean supply response time if a spare is available in shipboard stock;

MSRTW: wholesale system mean supply response time;

MSRTS: resupply mean supply response time;

ρ : probability that a spare is not available from shipboard stock (RISK);

$(1-\rho)$: protection level or the probability that a spare is available in shipboard stock.

Note that MSRTW must be greater than T4. If this is not the case then the protection level of the shipboard stock should be increased.

Since the objective of our model is to compute the wholesale stock level necessary to meet a specified MSRTG at the shipboard level we need to compute the expected number of backorders for the ship at a randomly selected time. Let $B_{ij}(SW_i, SS_{ij}; \theta_{ij})$ be the expected number of backorders for item i at a randomly selected time for ship j . Then:

$$TWUS_{ij} = B_{ij}(SW_i, SS_{ij}; \theta_{ij}) \quad (\text{eqn 5.13})$$

$$= \sum_{x_{ij} = SS_{ij} + 1}^{\infty} (x_{ij} - SS_{ij}) * p_{ij}(x_{ij}; \theta_{ij}),$$

where SS_{ij} : ship j stock level for item i , and

$\theta_{ij} = MSRTW_i * D_{ij}$ is the mean demand at ship j for

item i during an average resupply time and is a function of SW_i .

This expression can be rewritten as:

$$TWUS_{ij} = (\theta_{ij} - SS_{ij}) + \sum_{x_{ij}=0}^{SS_{ij}-1} (SS_{ij} - x_{ij}) * p_{ij}(x_{ij}; \theta_{ij}). \quad (\text{eqn 5.14})$$

Finally, if we divide the expected time-weighted units short, $TWUS_{ij}$, by the expected failure rate at ship j, D_{ij} , we get the average delay per failure or the mean supply response time for the ship. Then it follows that the average MSRT across all ships for item i is given by:

$$MSRT_i = \sum_{j=1}^J B_{ij}(SS_{ij}, SW_i; \theta_{ij}) / D_i, \quad (\text{eqn 5.15})$$

and $MSRT_i$ is constrained to be no larger than $MSRTG$.

To solve for SW_i which satisfies this goal we first select SS_{ij} values based on a shipboard stockage model. We also assume values for $T_1, T_2, T_3, T_4, T_5, RTAT, PLT$, and ALT . Finally we assume an initial value for $MSRTRS_i$ and hence the initial SW_i . Next we compute $MSRT_i$ using equation 5.15 and compare it to $MSRTG$. Then our model finds SW_i iteratively by adding or deleting units of stock at the whole-sale level until the MSRT first attains the specified goal.

The actual average supply system mean supply response time over all items, $MSRT_{ss}$, is then a weighted average of the I mean supply response times. That is:

$$MSRT_{ss} = \frac{\sum_{i=1}^I D_i * MSRT_i}{\sum_{i=1}^I D_i}. \quad (\text{eqn 5.16})$$

L. THE CONSTRAINED MODEL

The repairables model developed thus far assumed no limitations on funds available. This is seldom the situation. However, as developed, the MSRT repairables model would indicate how large the Navy Stock Fund must be in order to satisfy a desired MSRT goal.

If funds are limited, then the Navy must decide which items will reduce the difference between the amount needed and the budget while doing the least amount of damage to the actual MSRT goal.

Since there are certain weapon systems which are more critical than others, it is important that the essentiality of an item be taken into consideration when making this decision. For this purpose we shall use the Item Mission Essentiality code (IMEC) which is determined based on the component level Mission Criticality Code and the part level Military Essentiality Code.

The development of the IMEC is explained in [Ref. 1: p. 4-40]. The IMEC's are defined as follows:

IMEC	Definition
4	Loss of primary mission capability
3	Severe degradation of a primary mission capability
2	Loss of a secondary mission capability
1	Minor mission impact

It should be noted that the IMEC assigned to an item is not based on either an interval or ratio scale. Therefore, an item with an IMEC of 4 is not necessarily twice as important as an item with an IMEC of 2. But since these are the basis for the new essentiality codes being developed by the Navy, they were chosen for this model.

If there is a total of I items in the supply system, the new problem that must be solved given a cost constraint is to find the values of SW_i which:

$$\begin{aligned} &\text{minimize } \sum_{i=1}^I IMEC_i * D_i * MSRT_i(SW_i) \\ &\text{subject to } \sum_{i=1}^I C_i * SW_i \leq B \end{aligned}$$

Using the stock levels computed previously for the unconstrained problem, this new problem can be solved using marginal analysis by assigning a weighting factor to each unit of stock based on the cost, IMEC, and mean supply response time for the item. This leads to consideration of the ratio:

$$WT_i = C_i / (IMEC_i * MSRT_i), \quad (\text{eqn 5.17})$$

where: C_i : cost of item i ;

$IMEC_i$: IMEC associated with item i ;

$MSRT_i$: MSRT for item i based on a wholesale stock level of SW_i .

This weighting factor, WT , for each item can be used in an algorithm to reduce the costs until the total cost of stock is less than or equal to the budget. We start by deleting a unit of stock from the wholesale level for the item with the highest WT . After a unit of stock is deleted a new $MSRT$ and WT must be computed for that item before comparing WT values again. We again select that item having the largest WT and reduce its wholesale level by one unit. This process continues until we are within the budget limit. Except for some refinements that might be needed as the budget reduction process approaches the budget constraint, this method of trimming the stock levels will ensure that the supply system stocks those items that provide the lowest essentiality-weighted $MSRT$ per dollar invested.

M. APPLICATION TO CONSUMABLES

Even though the subject of this thesis is repairables, the above model is also easily applicable to consumables inventory management. Effectively this can be accomplished by setting the probability of repair (γ) equal to zero and setting the time required for the ICP to determine that a NRFI unit will not be returned by the ship (T_5) equal to zero. The result is a consumables model which is based on MSRT.

VI. MODEL RESULTS

In the previous chapter a repairables model which uses mean supply response time as a measure of effectiveness was developed. In this chapter we will provide some examples of this model in use.

A. COMPUTER PROGRAM

The computer program for this model is written in Fortran IV and was run on the IBM 3033 at the Naval Postgraduate School, Monterey, California. A flowchart of the program is provided in Appendix A and a listing of the Fortran program in Appendix B.

The data are stored in a separate data file and read into the program at execution time from file 5 (personal disk file). On the IBM 3033 under WATFIV, the program is compiled and executed by issuing the following command: WATFIV STOCK DATA (DISK. In this example the program listing file is named "STOCK" and the data file is named "DATA". The command "(DISK" causes the output to be written to output disk file 5 - "STOCK LISTING".

A description of a data file is provided in Appendix C. The program allows the user to either input data which are based on SPCC items or non-SPCC items. For either type of item, two different sets of parameters are read into the program. They are system parameters and item parameters. Table 1 provides a list and brief description of the input and output variables.

TABLE 1
Variable Descriptions

INPUT VARIABLES

NIIN: national item identification number
 COST: replacement cost of the item
 MSRTS: mean supply response time aboard ship
 T1: shipping time to NSC from ship
 T2: shipping time to DOP from NSC
 T3: shipping time to NSC from DOP or manufacture
 T4: shipping time to ship from NSC
 T5: time before ICP decides to procure
 ALT: procurement administrative lead time
 MSRT: desired system MSRT
 RISK: ship stock protection level
 D: system demand rate
 1-TAO: attrition rate
 PLT: production lead time
 R: repair batch size
 Q: procurement lot size
 RTAT: repair-turn-around-time
 BRP: best replacement factor
 IMEC: item mission essentiality code

OUTPUT VARIABLE

TT1: mean repair cycle time
 TT2: mean procurement cycle time
 U: mean wholesale resupply time
 MU: mean quantity in resupply
 MSRTW: MSRT wholesale goal
 MSRTWS: MSRT resupply goal
 1-RHO: actual protection level
 SS: shipboard stock level
 CMSRT: computed MSRT
 SW: computed wholesale stock level

B. SYSTEM PARAMETERS

This section provides an explanation of the system parameters and the values used in the examples.

MSRTS is the mean supply response time of the supply department if the item is stocked aboard the ship. Since [Ref. 1] specifies an MSRTS of 2 hours this parameter is input as 0.001 quarters.

T1 is the mean shipping time for a NRFI carcass from the ship to the collection point, in this case an NSC. In accordance with Uniform Material Movement and Issue Priority

G. THE EFFECTS OF THE BUDGET CONSTRAINT

Thus far our examples have all dealt with the effect on the stocking level of varying various input parameters while still being able to attain the desired mean supply response time of 125 hours. In all the above examples no budget constraints were imposed. However, as we know, the military establishment must function within a budget just like a corporation. A limiting budget would require the stocking of fewer units. As demonstrated by the previous examples, the Navy can attain its desired MSRT goal while stocking fewer units of each item if it adheres to one-for-one repair and procurement policies and/or by reducing the repair time of an item. However, even if these policies are in effect, the budget may still be constraining and we therefore need to know the effect on the overall mean supply response time of various values of such a budget. The following examples address this problem by using the concept of trimming stock levels based on cost, essentiality and MSRT discussed in Chapter V.

Our first example considers 10 SPCC items; not all of which are stocked at the shipboard level. This is determined by an item's best replacement factor and IMEC. The detailed input and output for this example with no budget constraint imposed are provided in Appendix D. A summary of those results without and with a budget constraint are provided in Table 11. As indicated in Table 11, to attain the desired MSRT of 125 hours the cost of stock required at the wholesale level is \$238,350.60. In fact, the actual value of MSRT is 97.25 hours (0.0450 quarters). When a budget constraint of \$100,000.00 is imposed at the wholesale level the resulting system MSRT is 1016.28 hours (0.4705 quarters).

In the second example we consider the same 10 items but as non-SPCC items with an MSRT goal of 0.05 quarters. All

TABLE 10
Effects of Carried vs Not Carried

	MODEL INPUT			
NIIN	11111111	11111111	22222222	22222222
COST	1000.00	1000.00	1000.00	1000.00
MSRTS	0.0010	0.0010	0.0010	0.0010
TT1	0.5000	0.5000	0.5000	0.5000
TT2	0.3000	0.3000	0.3000	0.3000
TT3	0.2500	0.2500	0.2500	0.2500
TT4	0.0500	0.0500	0.0500	0.0500
TT5	1.0000	1.0000	1.0000	1.0000
ALT	2.0000	2.0000	2.0000	2.0000
MSRT	0.0579	0.0579	0.0579	0.0579
RISK	0.1000	1.0000	0.1000	1.0000
D ***	4.0000	4.0000	0.1000	0.1000
1-TAU	0.0500	0.0500	0.0500	0.0500
PLT	4.5000	4.5000	4.5000	4.5000
R	1.0	1.0	1.0	1.0
Q	1.0	1.0	1.0	1.0
RTAT	1.5000	1.5000	1.5000	1.5000
BRF	0.3000	0.0200	0.0500	0.0200
IMEC	4.0	2.0	4.0	2.0
MODEL OUTPUT				
TT1	2.5500	2.5500	2.5500	2.5500
TT2	7.7500	7.7500	7.7500	7.7500
U	2.8100	2.8100	2.8100	2.8100
MU	11.2400	11.2400	0.2810	0.2810
MSRTW	1.1400	0.0557	0.4103	0.0522
MSRTS	1.0900	0.0057	0.3603	0.0022
1-RHC	0.9084	0.0000	0.9992	0.0000
SS	7.	0.	1.	0.
CMSRT	0.0411	0.05570	0.0083	0.0522
SW	7.	19.	1.	3.

*** Parameters being varied

Also, in both cases the total Navy investment, shipboard stock plus wholesale stock, is less when the item is stocked at the shipboard level. Hence, the Navy saves not only on transportation cost as noted above, but also in the total quantity of stock that must be procured.

This is not to say that all items can be stocked at the shipboard level. Many other factors must be taken into consideration in making this decision and this inventory model is not designed to make those decisions.

E. EFFECTS OF VARYING ALT

The administrative lead time (ALT) is the time required to put together the ordering data and award the purchase order or contract for a replacement item. In all the above examples ALT was set at two quarters. To determine if varying ALT would affect the required stock level, these same examples were repeated using an ALT of one quarter. There was very little effect on any of the stocking levels. This is probably the result of the low attrition rate (5 percent) used. But, for repairable items a low attrition is expected. In fact, in many repairables models such as METRIC, discussed in Chapter IV, attrition is assumed to be zero.

F. CARRIED VERSUS NOT CARRIED

If a repairable item is stocked at the shipboard level and all requisitions submitted to the wholesale system are for stock replenishment, then the Navy saves on transportation cost. Specifically, less expensive modes of transportation can be used if the expected shipping time is 45 days for a stock replenishment demand vice five days for an immediate use demand. How does this savings in transportation cost translate into savings in wholesale stock level requirements? To find out, we consider two SPCC items, one with a system demand rate of four per quarter and the other with a system demand rate of 0.1 per quarter and change the value of RISK from 0.10 to 1.0. When the value of RISK=1.0, the protection at the shipboard level is zero and all demand is immediate use demand.

As indicated in Table 10 for the item with a demand rate of four, the wholesale system must stock twelve additional units when the item is not stocked aboard ship. For the item with a demand rate of 0.1 the system must stock two additional units when no shipboard support is provided.

TABLE 9
Effects of Varying PLT and RTAT (Case 3)

	MODEL INPUT			
NIIN	111111111	111111111	111111111	111111111
COST	1000.00	1000.00	1000.00	1000.00
MSRTS	0.0010	0.0010	0.0010	0.0010
T1	0.5000	0.5000	0.5000	0.5000
T2	0.3000	0.3000	0.3000	0.3000
T3	0.2500	0.2500	0.2500	0.2500
T4	0.0500	0.0500	0.0500	0.0500
T5	1.0000	1.0000	1.0000	1.0000
ALT	2.0000	2.0000	2.0000	2.0000
MSRT	0.0579	0.0579	0.0579	0.0579
RISK	0.1000	0.1000	0.1000	0.1000
D	4.0000	4.0000	4.0000	4.0000
1-TAU	0.0500	0.0500	0.0500	0.0500
PLT ***	4.5000	2.2500	4.5000	2.2500
R	1.0	1.0	1.0	1.0
O	1.0	1.0	1.0	1.0
RTAT ***	1.5000	1.5000	0.7500	0.7500
IMEC	4.0	4.0	4.0	4.0
	MODEL OUTPUT			
TT1	2.5500	2.5500	1.8000	1.8000
TT2	7.7500	5.5000	7.7500	5.5000
U	2.8100	2.6975	2.0975	1.9850
MU	11.2400	10.7900	8.3900	7.9400
MSRTW	1.1400	1.0363	1.1587	1.0505
MSRTS	1.0900	0.9863	1.1087	1.0050
1-RHO	0.9084	0.9398	0.9019	0.9359
SS	7.	7.	7.	7.
CMSRT	0.0411	0.0255	0.0445	0.0273
SW	7.	7.	4.	4.

*** Parameters being varied

phase of a new weapon system to establish allowance lists of repair parts for maintenance activities or to stock repair parts which do not qualify to be stocked aboard ship. Hence, this lack of repair parts support results in longer repair times. As is shown by the above examples, if the repair-turn-around-time could be reduced, the amount of stock required at the wholesale level could be reduced.

TABLE 8
Effects of Varying PLT and RTAT (Case 2)

	MODEL INPUT			
NIIN	111111111	111111111	111111111	111111111
COST	1000.00	1000.00	1000.00	1000.00
MSRTS	0.0010	0.0010	0.0010	0.0010
T1	0.5000	0.5000	0.5000	0.5000
T2	0.3000	0.3000	0.3000	0.3000
T3	0.2500	0.2500	0.2500	0.2500
T4	0.0500	0.0500	0.0500	0.0500
T5	1.0000	1.0000	1.0000	1.0000
ALT	2.0000	2.0000	2.0000	2.0000
MSRT	0.0579	0.0579	0.0579	0.0579
RISK	0.1000	0.1000	0.1000	0.1000
D	0.1000	0.1000	0.1000	0.1000
1-TAU	0.0500	0.0500	0.0500	0.0500
PLT ***	4.5000	2.2500	4.5000	2.2500
R	1.0	1.0	1.0	1.0
O	1.0	1.0	1.0	1.0
RTAT ***	1.5000	1.5000	0.7500	0.7500
BRF	0.0500	0.0500	0.0500	0.0500
IMEC	4.0	4.0	4.0	4.0
	MODEL OUTPUT			
TT1	2.5500	2.5500	1.8000	1.8000
TT2	7.7500	5.5000	7.7500	5.5000
U	2.8100	2.6975	2.0975	1.9850
MU	0.2810	0.2697	0.2097	0.1985
MSRTW	0.4103	0.3832	0.2554	0.2346
MSRTS	0.3603	0.3332	0.2054	0.1846
1-RHO	0.9992	0.9993	0.9997	0.9997
SS	1.	1.	1.	1.
CHSRT	0.0083	0.0072	0.0032	0.0027
SW	1.	1.	1.	1.

*** Parameters being varied

demand rate of four per quarter. The results are displayed in Table 9 which indicates that cutting the PLT had no effect, but cutting the RTAT resulted in a reduction of three units.

As stated above, the ICP usually has very little control over the PLT or RTAT. Often the RTAT at a Navy DOP may be affected by the availability of repair parts stocked locally or available in the supply system. As was stated in Chapter II, very little is done by the Navy during the provisioning

TABLE 7
Effects of Varying PLT and RTAT (Case 1)

	MODEL INPUT			
NIIN	111111111	111111111	111111111	111111111
COST	1000.00	1000.00	1000.00	1000.00
MSRTS	0.0010	0.0010	0.0010	0.0010
T1	0.5000	0.5000	0.5000	0.5000
T2	0.3000	0.3000	0.3000	0.3000
T3	0.2500	0.2500	0.2500	0.2500
T4	0.0500	0.0500	0.0500	0.0500
T5	1.0000	1.0000	1.0000	1.0000
ALT	2.0000	2.0000	2.0000	2.0000
MSRT	0.0579	0.0579	0.0579	0.0579
RISK	0.1000	0.1000	0.1000	0.1000
D	4.0000	4.0000	4.0000	4.0000
1-TAU	0.0500	0.0500	0.0500	0.0500
PLT ***	4.5000	2.2500	4.5000	2.2500
R	1.0	1.0	1.0	1.0
O	1.0	1.0	1.0	1.0
RTAT ***	1.5000	1.5000	0.7500	0.7500
BRF	0.3000	0.3000	0.3000	0.3000
IMEC	4.0	4.0	4.0	4.0
	MODEL OUTPUT			
TT1	2.6050	2.5500	1.8000	1.8000
TT2	7.7500	5.5000	7.7500	5.5000
U	2.8622	2.6975	2.0975	1.9850
MU	11.4490	10.7900	8.3900	7.9400
MSRTW	0.5500	1.0363	1.1587	1.0505
MSRTS	0.5000	0.9863	1.1087	1.0050
1-RHO	0.9084	0.9398	0.9019	0.9359
SS	7.	7.	7.	7.
CMSRT	0.0411	0.0255	0.0445	0.0273
SW	7.	7.	4.	4.

*** Parameters being varied

Case two assumes that the item is an SPCC item which is stocked at the shipboard level and has a system wide demand rate of 0.1 per quarter. As seen in Table 8 there was no saving in this case because the results in the first column (the base case) required only one unit to be stocked and changes in the PLT and RTAT did not reduce the required stock level to zero.

Case three assumes that the item is a non-SPCC item with a 90 percent shipboard protection level and a system wide

TABLE 6
Effects of Varying R and Q (Case 4)

	MODEL INPUT			
NIIN	111111111	111111111	111111111	111111111
COST	1000.00	1000.00	1000.00	1000.00
MSRTS	0.0010	0.0010	0.0010	0.0010
T1	0.5000	0.5000	0.5000	0.5000
T2	0.3000	0.3000	0.3000	0.3000
T3	0.2500	0.2500	0.2500	0.2500
T4	0.0500	0.0500	0.0500	0.0500
T5	1.0000	1.0000	1.0000	1.0000
ALT	2.0000	2.0000	2.0000	2.0000
MSRT	0.0579	0.0579	0.0579	0.0579
RISK	0.1000	0.1000	0.1000	0.1000
D	0.1000	0.1000	0.1000	0.1000
1-TAU	0.0500	0.0500	0.0500	0.0500
PLT	4.5000	4.5000	4.5000	4.5000
R ***	1.0	4.0	1.0	4.0
Q ***	1.0	1.0	4.0	4.0
RTAT	1.5000	1.5000	1.5000	1.5000
IMEC	4.0	4.0	4.0	4.0
	MODEL OUTPUT			
TT1	2.5995	18.3950	2.5500	18.3395
TT2	7.7500	7.7500	307.7498	307.7498
U	2.8100	17.8100	17.8100	32.8100
MU	0.2810	1.7810	1.7810	3.2810
MSRTW	0.0522	0.0564	0.0564	0.0520
MSRTS	0.0022	0.0064	0.0064	0.0020
1-RHO	0.0000	0.0000	0.0000	0.0000
SS	0.	0.	0.	0.
CMSRT	0.522	0.0564	0.0564	0.0520
SW	3.	7.	7.	11.

*** Parameters being varied

Case one assumes that the item is an SPCC item which is stocked at the shipboard level and has a system wide demand rate of four per quarter. The base case uses a PLT equal to 4.5 quarters and RTAT of 1.5 quarters. The results are provided in Table 7 which indicates that cutting the PLT in half does not affect the wholesale stock required but cutting the RTAT in half reduces that stock requirement by three units.

TABLE 5
Effects of Varying R and Q (Case 3)

	MODEL INPUT			
NIIN	111111111	111111111	111111111	111111111
COST	1000.00	1000.00	1000.00	1000.00
MSRTS	0.0010	0.0010	0.0010	0.0010
T1	0.5000	0.5000	0.5000	0.5000
T2	0.3000	0.3000	0.3000	0.3000
T3	0.2500	0.2500	0.2500	0.2500
T4	0.0500	0.0500	0.0500	0.0500
T5	1.0000	1.0000	1.0000	1.0000
ALT	2.0000	2.0000	2.0000	2.0000
MSRT	0.0579	0.0579	0.0579	0.0579
RISK	0.1000	0.1000	0.1000	0.1000
D	4.0000	4.0000	4.0000	4.0000
1-TAU	0.0500	0.0500	0.0500	0.0500
PLT	4.5000	4.5000	4.5000	4.5000
R ***	1.0	4.0	1.0	4.0
Q ***	1.0	1.0	4.0	4.0
RTAT	1.5000	1.5000	1.5000	1.5000
IMEC	4.0	4.0	4.0	4.0
	MODEL OUTPUT			
TT1	2.5500	2.9447	2.5500	2.9447
TT2	7.7500	7.7500	15.2500	15.2500
U	2.8100	3.1850	3.1850	3.5600
MU	11.2400	12.7400	12.7400	14.2400
MSRTW	1.1400	1.0407	1.0407	1.1601
MSRTS	1.0900	0.9907	0.9907	1.1100
1-RHO	0.9084	0.9386	0.9386	0.9014
SS	7.	7.	7.	7.
CMSRT	0.0411	0.0261	0.0261	0.0448
SW	7.	9.	9.0	10.

*** Parameters being varied

D. EFFECTS OF VARYING RTAT AND PLT

Usually the ICP does not have any control over the length of time it takes to repair an item (RTAT) or the manufacturer's production lead time (PLT). Nevertheless, the following test cases were run to determine the effect on the stocking level if these times were decreased by one-half. In these cases $Q=R=1.0$ corresponding to no batching for either procurement or repair.

TABLE 4
Effects of Varying R and Q (Case 2)

	111111111	MODEL INPUT 111111111	111111111	111111111
NIIN	1000.00	1000.00	1000.00	1000.00
COST	0.0010	0.0010	0.0010	0.0010
MSRTS	0.5000	0.5000	0.5000	0.5000
T1	0.3000	0.3000	0.3000	0.3000
T2	0.2500	0.2500	0.2500	0.2500
T3	0.0500	0.0500	0.0500	0.0500
T4	1.0000	1.0000	1.0000	1.0000
T5	2.0000	2.0000	2.0000	2.0000
ALT	0.0579	0.0579	0.0579	0.0579
MSRT	0.1000	0.1000	0.1000	0.1000
RISK	0.1000	0.1000	0.1000	0.1000
D	0.0500	0.0500	0.0500	0.0500
1-TAU	4.5000	4.5000	4.5000	4.5000
PLT	1.0	1.0	1.0	1.0
R ***	1.0	1.0	1.0	1.0
Q ***	1.5000	1.5000	1.5000	1.5000
RTAT	0.0500	0.0500	0.0500	0.0500
BRF	4.0	4.0	4.0	4.0
IMEC				
		MODEL OUTPUT		
TT1	2.5500	18.3395	2.5500	18.3395
TT2	7.7500	7.7500	307.7498	307.7498
U	2.8100	17.8100	17.8100	32.8100
MU	0.2810	1.7810	1.7810	3.2810
MSRTW	0.4103	0.5301	0.5301	0.8350
MSRTS	0.3603	0.4801	0.4801	0.7850
1-RHO	0.9992	0.9986	0.9986	0.9967
SS	1.	1.	1.	1.0
CMSRT	0.0083	0.0138	0.0138	0.0339
SW	1.	4.	4.	6.

*** Parameters being varied

Even though the quantities added to the repair batch size or procurement lot do not result in a one-for-one increase at the wholesale stock level as they did for the deterministic case, these four examples again indicate that additional stock must be carried to support such repair and procurement policies. Hence, the cost of batching is the additional investment in extra units of stock required to achieve the specified effectiveness.

TABLE 3
Effects of Varying R and Q (Case 1)

	MODEL INPUT			
NIIN	11111111	11111111	11111111	11111111
COST	1000.00	1000.00	1000.00	1000.00
MSRTS	0.0010	0.0010	0.0010	0.0010
T1	0.5000	0.5000	0.5000	0.5000
T2	0.3000	0.3000	0.3000	0.3000
T3	0.2500	0.2500	0.2500	0.2500
T4	0.0500	0.0500	0.0500	0.0500
T5	1.0000	1.0000	1.0000	1.0000
ALT	2.0000	2.0000	2.0000	2.0000
MSRT	0.0579	0.0579	0.0579	0.0579
RISK	0.1000	0.1000	0.1000	0.1000
D	4.0000	4.0000	4.0000	4.0000
1-TAU	0.0500	0.0500	0.0500	0.0500
PLT	4.5000	4.5000	4.5000	4.5000
R ***	1.0	1.0	1.0	1.0
Q ***	1.0	1.0	1.0	1.0
RTAT	1.5000	1.5000	1.5000	1.5000
BRF	0.3000	0.3000	0.3000	0.3000
IMEC	4.0	4.0	4.0	4.0
	MODEL OUTPUT			
TT1	2.5500	2.9447	2.5500	2.9447
TT2	7.7500	7.7500	15.2500	15.2500
U	2.8100	3.1850	3.1850	3.5600
MU	11.2400	12.7400	12.7400	14.2400
MSRTW	1.1400	1.0407	1.0407	1.1601
MSRTS	1.0900	0.9907	0.9907	1.1101
1-RHO	0.9084	0.9386	0.9386	0.9014
SS	7.	7.	7.	7.
CMSRT	0.0411	0.261	0.261	0.0448
SW	7.	9.0	9.0	10.0

*** Parameters being varied

stocked. If both are set at four then three additional units are needed.

Case four assumes a non-SPCC item with a 90 percent shipboard protection level and a system wide demand rate of 0.1 per quarter. The results are provided in Table 6 which indicates that if either a repair batch size (R) or procurement lot size (Q) of four is specified then an additional four units above the no-batching level must be stocked. If both are set at four then eight additional units are needed.

C. EFFECTS OF VARYING R AND Q

When we developed the deterministic version of the repairables model in Chapter V, we pointed out that one-for-one ordering and repair policies should be followed unless other economic reasons precluded such policies. To determine the effect of batching for repair or procurement on the wholesale stock level the following test cases were tried.

Case one assumes one item and that it is an SPCC item which is stocked at the shipboard level and has a system wide demand rate, D , of four per quarter. The results are presented in Table 3. The first column presents the results for no batching (i.e. $Q=R=1.0$). The wholesale stock is 7 units. The next three columns have either a repair or procurement lot size of 4.0. If either a repair batch size (R) or a procurement lot size (Q) of four is specified then nine units of that item must be stocked in the wholesale system; an increase of two units above the no-batching level. If both are set at four then ten units must be stocked; an increase of three units over the no-batching level.

Case two assumes that the item is an SPCC item which is stocked at the shipboard level and has a system wide demand rate of 0.1 per quarter. The results are provided in Table 4 which indicates that if either a repair batch size (R) or a procurement lot size (Q) of four is specified then three units above the no-batching level must be stocked. If both are set at four, then five additional units are needed.

Case three assumes a non-SPCC item with a 90 percent shipboard protection level and a system wide demand rate of four per quarter. The results are provided in Table 5 which indicates that if either a repair batch size (R) or a procurement lot size (Q) of four is specified then an additional two units above the no-batching level must be

TABLE 2
Actual Protection Levels

Demand Rate	Shipboard Stock Level	Actual Protection (90 days)	Actual Protection (45 days)
0.25/qtr.	1	0.9735	0.9928
1.0/qtr.	2	0.9197	0.9856
4.0/qtr.	7	0.9485	0.9989
10.0/qtr.	14	0.9165	0.9998
.0625/qtr.*	1	0.9981	0.9995

* carried as an insurance item

ALT is the administrative lead time required for SPCC to prepare a purchase order or contract and the ordering data for replacement item procurement. The current ALT used by SPCC is 2 quarters. Hence, 2 quarters is used for most runs unless otherwise specified.

BUDGET is the authorized level of the Navy Stock Fund. This parameter is varied to demonstrate the effects of the budget constraint.

All time parameters are input as quarters. It should also be noted that no time is allowed for the preparation of work orders for repair actions. Since we have assumed that all repairable items have an established DOP, we have further assumed that a DOP will be prepared to immediately accept any items shipped for repair by SPCC. Also, to simplify computations, we have assumed only one ship and have used the quarterly demand rate D_i for computing the shipboard stock level. In actual practice the best replacement factor and installed population of the item should be used instead.

Since UMMIPS instructions establish 45 days as the mean shipping time for stock replenishment requisitions, the program uses a 45 day mean supply response time for the resupply cycle (MSRTRS). If an item is stocked at the shipboard level at a 90 percent protection level, then the remaining 10 percent must be furnished by the wholesale system. So 10 percent of the requirements for an item authorized to be stocked aboard ship are ordered by a higher priority requisition for "immediate use", having an established shipping time, T_4 , of 0.05 quarters. Therefore, to compute the initial estimate for SW, we use MSRTRS equal to 45 days (0.5 quarters).

For the items not carried at the shipboard level a MSRTRS of 0.0079 quarters is used since all demands are for immediate use and the mean shipping time is 0.05 quarters for these demands. These sum to the MSRT goal of 0.0579 quarters (125 hours).

RISK is the probability that an item will not be available at the shipboard level when needed. Since Navy ships stock those items authorized to be stocked at a 90 percent protection level for 90 days, the parameter for RISK is set at 10 percent. However, it should be noted that the actual risk is lower than 10 percent for stocked items assuming that they are replenished 90 days after the demand has occurred. This happens because the stock levels, which are integer values, are computed using the Poisson distribution. If the replenishment time is less than 90 days, the actual risk is even lower. For example, if the requested item is available at the wholesale level immediately and the only delay is the 45 day shipping time the actual risk is very small. Using the Poisson distribution for demand, the actual protection level for various demand rates at both 90 day and 45 day replenishment times are provided in Table 2.

System (UMMIPS) instructions [Ref. 8] the expected shipping time is 45 days, hence the parameter used is 0.5 quarters.

T2 is the mean shipping time from the NSC to the DOP. An estimate of 0.3 quarters (27 days) is used for this parameter.

T3 is the mean shipping time from the DOP or a manufacture to the NSC for an RFI item. An estimate of 0.25 quarters (22.5 days) is used for this parameter.

T4 is the mean shipping time from the NSC to the ship if the material is for immediate use. According to UMMIPS standards [Ref. 8] this time should vary between 4 to 6 days. A value of 0.05 quarters (4.5 days) is used in our examples.

T5 is the mean time before the ICP determines that a carcass will not be returned after a demand for a replacement item is received. As described in Chapter II, SPCC initiates follow up actions on turn-ins after 75 days. If a reply of shipping status is not received within 20 days then SPCC considers that a carcass will not be returned. An estimate of 1.0 quarter (90 days) is used for this parameter.

MSRT is the mean supply response time goal. For SPCC items where a goal of 125 hours has been established in CONUS (135 hours EXCONUS) for issue priority groups I and II this parameter is included in the program along with a decision routine for determining if an item is authorized to be stocked at the shipboard level.

For Navy ships, if an item has an expected demand greater than one per year based on the best replacement factor for the item, then it is stocked at the shipboard level at a 90 percent protection level for 90 days. Also, using a simplified version of MODFLSIP, if an item has an expected demand of greater than one in ten years and an IMEC of 3 or 4, then one minimum replacement unit of the item it is stocked at the shipboard level as an insurance item.

TABLE 11
SPCC Items With Constraint

NIIN	UNCONSTRAINED		SS	CONSTRAINED	
	SW	MSRT		SW	MSRT
111111111*	5	0.0528	7	4	0.1233
222222222*	17	0.0542	10	15	0.1694
333333333*	3	0.0168	2	2	0.3796
444444444	4	0.0558	0	4	0.0558
555555555*	3	0.0303	5	3	0.0303
666666666*	27	0.0381	12	26	0.0744
777777777	12	0.0574	0	3	1.3158
888888888	6	0.0536	0	5	11.7042
999999999*	2	0.0242	1	1	1.2583
123456789*	1	0.0020	1	0	0.1592
SYSTEM MSRT:		0.0450			0.4705
TOTAL COST:	\$238,350.60			\$95,286.00	

* Stocked aboard ship

items have a shipboard protection level of 90 percent. The detailed input and output are provided in Appendix E and are summarized in Table 12. For this example the MSRT goal is attained at a cost to the wholesale system of \$127,920.00. (The actual system MSRT being 87.70 hours.) When the budget constraint of \$100,000.00 is imposed at the wholesale level the MSRT increases to 0.0599 quarters (129.38 hours).

Note that the required budget for the wholesale system in the first example is higher than the second example even though we considered the same 10 items. The reason being that some of the SPCC items are not stocked at the shipboard level whereas all the items in the second example are stocked at a 90 percent protection level. The second example would require much more stock at the shipboard level, and consequently, less at the wholesale level.

Since the goal of the Navy is to satisfy 65 percent of demands for all items including those not authorized to be

TABLE 12
NON-SPCC Items With Constraint (90 % protection)

NIIN	UNCONSTRAINED SW	MSRT	SS	CONSTRAINED SW	MSRT
1111111111	5	0.0528	7	5	0.0528
2222222222	17	0.0542	10	17	0.0542
3333333333	3	0.0168	2	3	0.0168
4444444444	2	0.0103	1	2	0.0103
5555555555	3	0.0303	5	3	0.0303
6666666666	27	0.0381	12	27	0.0381
7777777777	4	0.0257	5	2	0.2144
8888888888	3	0.0187	1	3	0.0187
9999999999	2	0.0242	1	2	0.0242
123456789	3	0.0504	0	3	0.0504
SYSTEM MSRT:		0.0406			0.0599
TOTAL COST:	\$127,920.00			\$99,070.06	

stocked at the shipboard level, the second example was repeated using a shipboard protection level of 65 percent. The detailed results are provided in Appendix F and summarized in Table 13. This time the MSRT goal is attained at a cost of \$170,744.80. (The actual system MSRT is 70.85 hours.) Adding the budget constraint of \$100,000.00 increased the MSRT to 0.2742 quarters (592.27 hours).

From these three examples we can determine the average cost associated with improving MSRT. In the first example the MSRT increased 919.08 hours when the budget was reduced by \$143,064.60. Thus for this group of items one hour of improvement in system MSRT would cost on the average \$155.66. Likewise, in the other two examples the cost per hour of MSRT is \$692.04 and \$150.93, respectively.

H. SUMMARY

This chapter has presented the results of applying the repairables model developed in Chapter V to several

TABLE 13
NON-SPCC Items With Constraint (65 % protection)

NIIN	UNCONSTRAINED		SS	CONSTRAINED	
	SW	MSRT		SW	MSRT
1111111111	7	0.0360	5	7	0.0360
2222222222	20	0.0424	7	20	0.0424
3333333333	4	0.0276	1	4	0.0276
4444444444	4	0.0558	0	4	0.0558
5555555555	5	0.0183	3	5	0.0183
6666666666	29	0.0326	10	29	0.0326
7777777777	6	0.0175	3	1	0.9269
8888888888	3	0.0187	1	2	1.5905
9999999999	5	0.0525	0	5	0.0525
123456789	3	0.0504	0	2	0.0525
SYSTEM MSRT:		0.0328			0.2742
TOTAL COST:	\$170,744.80			\$92,045.13	

examples. We have shown that the wholesale stock levels can be reduced if batching for repair or procurement is not required and if the RTAT can be decreased. Also, we have shown that by knowing and including the shipboard stock level vice assuming it to be zero, we greatly reduce the amount of stock required in the wholesale system.

This model can be used as a budgeting tool to determine the total dollar value of the Navy Stock Fund necessary to attain a predetermined MSRT goal. If a budget constraint is imposed this model is also capable of computing the wholesale stock level for each item in such a manner that the minimum MSRT is achieved for the budget available.

Since this model uses MSRT as the measure of effectiveness, and since it integrates the shipboard stockage levels into the wholesale stock determination computations, we consider it an appropriate model for use by the Navy for repairables inventory management. Also, as noted in Chapter V, this model is capable of computing stock levels for consumable items by changing merely one input parameter.

VII. SUMMARY AND RECOMMENDATIONS

A description of the repairables cycle in the Navy supply system was presented in Chapter II. It is evident from this description that the repairables cycle is very complex and presents many problems which must be dealt with for any inventory model to be of value to the supply system. Any inventory model used by the Navy must rely on the data maintained in the UICP files. Therefore, the integrity of these files and the validity of the data cannot be over emphasized.

Chapter III provided a detailed description of the current cost-oriented inventory repairables models used by SPCC. Further, we described the two repair scheduling methods, workload forecasting and recommendations generated by the B08 program, and how procurement decisions to replenish items lost through attrition are independent of the repair decisions. Finally, we showed how the current repair and procurement models are being integrated in an attempt to overcome the carcass constraint situation that has existed in the past.

The Navy, as was discussed in Chapter IV, has realized the need to move away from cost oriented models and is currently reviewing other models. Most of the models under review are performance oriented models. The one the Fleet Material Support Office considers the most promising is ACIM. Hence, Chapter V gives a description of both ACIM and the first readiness oriented model used by the military services, METRIC. However, both of these models are difficult from a computational view point and they both are very time consuming to run.

In Chapter V we developed a repairables model which uses mean supply response time as an objective function. This model not only considers the repairables cycle as described in Chapter II, but it also incorporates shipboard stocking policies when computing the wholesale stock levels. The wholesale stock level includes all items, both RFI and NRFI in the wholesale system.

In Chapter VI we demonstrated this repairables model and showed that the wholesale stock level of an item can be greatly affected by the repair and procurement policies in effect; i.e. a lower stock level is required if one-for-one repair and procurement policies are used. Also, by reducing the repair time required for an item, the stock level can be reduced. This suggests that when a repairable item is initially purchased and installed aboard ship, more consideration should be given to the repair parts support provided to the repair activity. By making the necessary repair parts available either at the repair activity or in the supply system, the repair time could be reduced. Hence, a savings could be realized in the number of spares that must be stocked at the wholesale level.

Additionally, we showed that by increasing the shipboard stock level in our computations, the stock required by the wholesale system was greatly reduced.

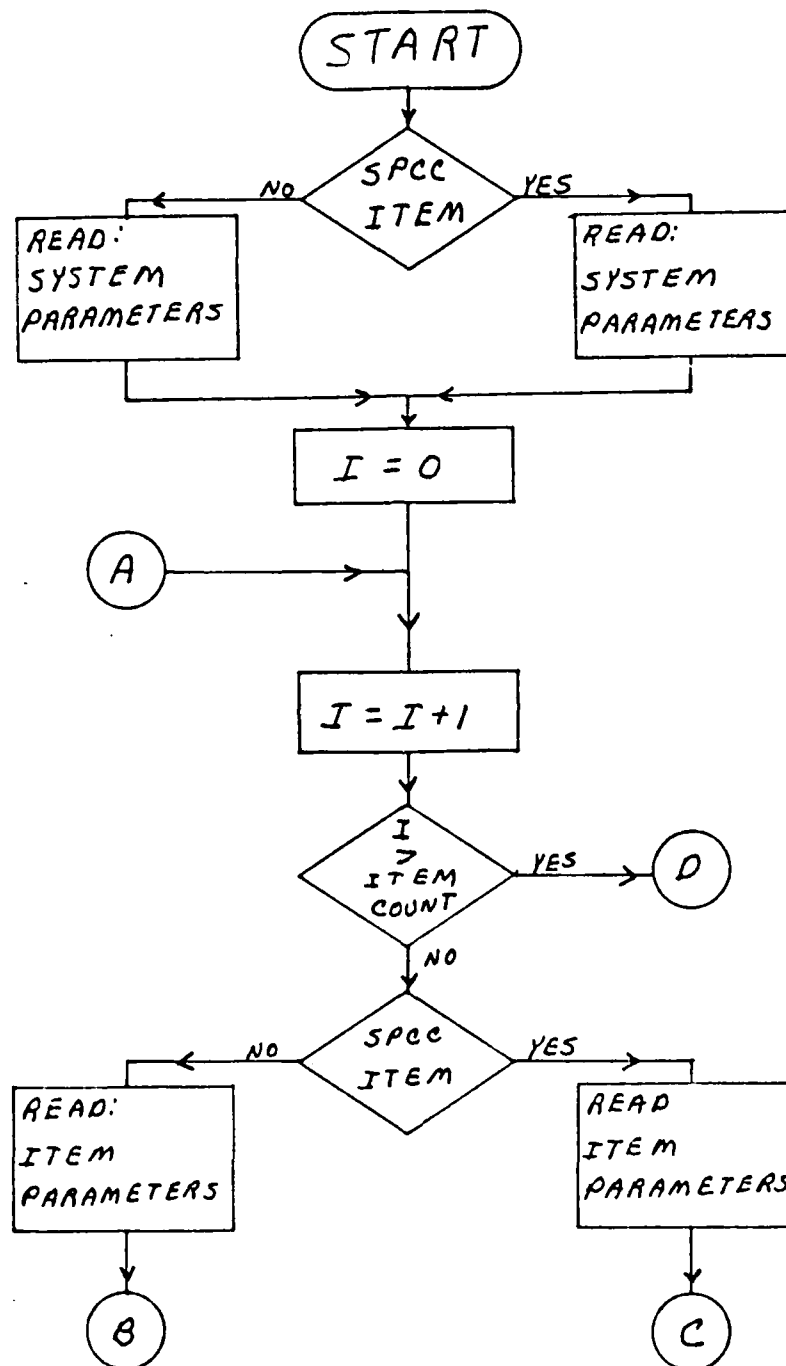
Finally, we explained how the model developed in Chapter V can be used as a budgeting tool when a mean supply response time goal has been specified. Further, this model is capable of solving the problem of determining stock levels which minimize the system MSRT given a budget constraint.

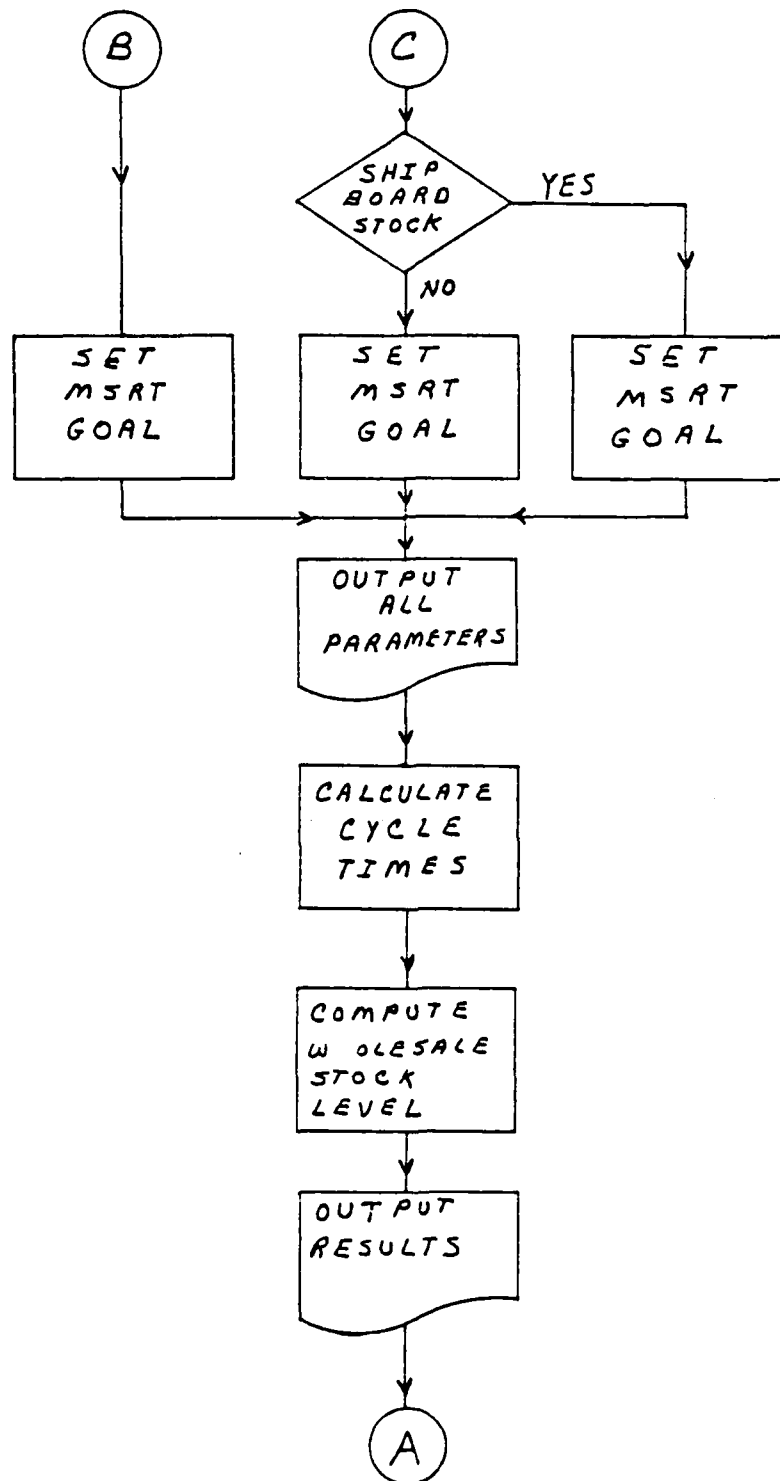
In Chapter VI we used this model to demonstrate the effects that varying different input parameters has on the required wholesale stock levels. However, our simplified examples assumed a one ship Navy where the total system

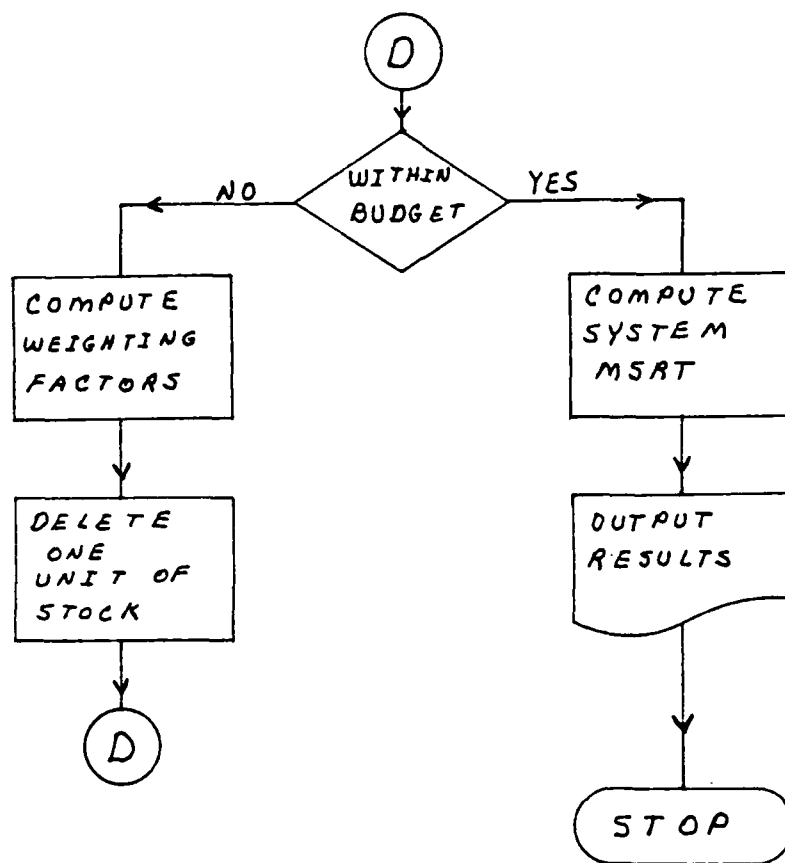
demand for an item resulted from that one ship. Since the Navy has many ships, each with their own unique equipment configuration, the total demand for an item is the sum of several unique demand rates. Therefore, this model should be tested to determine the best implementation procedures of a multiple ship Navy. A particular need is to determine the best way to estimate the shipboard failure rates. Also, after determining the best implementation procedures, this model should be compared against other multi-echelon repairables inventory models. This comparison should focus on two points: the inventory cost to attain the desired objective and the model's computational efficiency.

To refine the results, additional data should be collected for times required to complete each segment of the repairables cycle. Finally, since this model is capable of being used as a consumables model, additional research should be done in this area.

APPENDIX A
FLOWCHART OF MODEL







APPENDIX B PROGRAM LISTING OF REPAIRABLES MODEL

```

*****
** THIS PROGRAM COMPUTES THE WHOLESAL *
** STOCK QUANTITY FOR REPAIRABLES IN *
** THE NAVY SUPPLY SYSTEM. THE QUANTITY *
** COMPUTED INCLUDES RFI, NRFI, AND *
** STOCK IN TRANSIT. *****
*****
***** VARIABLES DESCRIPTION *****
ALT : ADMIN LEAD TIME REQUIRED FOR THE ICP TO PREPARE
AVMSRT: THE AVERAGE MEAN SUPPLY RESPONSE TIME FOR ALL
      ITEMS.
BRF : THE ESTIMATED FAILURE RATE OF ONE UNIT OVER
      A YEAR.
BUDGET: EITHER THE TOTAL BUDGET AUTHORIZED OR THE BUDGET
      NEEDED TO ATTAIN THE COMPUTED MSRT.
CDF : CUMULATIVE POISSON PROBABILITY.
CMSRT : COMPUTED MEAN SUPPLY RESPONSE TIME FOR THE
      COMPUTED STOCK LEVEL (SW).
COST : THE REPLACEMENT COST OF AN ITEM.
CUM : CUMULATIVE POISSON PROBABILITY.
DEM : DEMAND FOR A ITEM.
DEM : POISSON PARAMETER FOR COMPUTING SHIPBOARD RISK.
EXCESS: THE DIFFERENCE BETWEEN THE REQUIRED BUDGET AND
      THE AUTHORIZED BUDGET.
FUNC : EXPECTED NUMBER OF BACKORDERS AT THE WHOLESALF
      LEVEL AT A RANDOM POINT IN TIME.
FUNC1 : EXPECTED NUMBER OF BACKORDERS AT THE SHIPBOARD
      LEVEL AT A RANDOM POINT IN TIME.
GOAL : THE GOAL USED IN COMPUTING SW.
HIGH : VARIABLE USED TO DETERMINE HIGHEST WEIGHT (WT)
      WHEN ITEMS MUST BE DELETED DUE TO BUDGET CONSTRAINT.
I : INDEX VARIABLE.
IFLAG : FLAG USED TO DETERMINE WHETHER OR NOT TO USE
      SPCC PARAMETERS.
IMEC : ITEM MISSION ESSENTIALITY CODE - COMBINATION OF
      MISSION CRITICALITY CODE AND MILITARY
      ESSENTIALITY CODE.

```

J	INDEX VARIABLE.
K	INDEX VARIABLE.
MSRT	MEAN SUPPLY RESPONSE TIME GOAL AT SHIPBOARD LEVEL.
MSRTS	MEAN SUPPLY RESPONSE TIME FOR RESUPPLY PIPELINE.
MSRTS	MEAN SUPPLY RESPONSE TIME AT SHIPBOARD LEVEL GIVEN SPARE IS CARRIED ON BOARD.
MSRTW	MEAN SUPPLY RESPONSE TIME AT WHOLESALE LEVEL.
MU	RESUPPLY RATE WHOLESALE.
MULT	MULTIPLIER USED TO COMPUTE POISSON PROBABILITIES.
MUTEMP	DUMMY VARIABLE USED IN COMPUTING NEW MU.
N	INDEX VARIABLE.
NIIN	NATIONAL ITEM IDENTIFICATION NUMBER.
PLT	PRODUCTION LEADTIME FOR A PROCUREMENT LOT.
PROB	DUMMY VARIABLE USED IN COMPUTING NEW PSW.
PSS	POISSON PROBABILITY.
PSW	POISSON PROBABILITY.
PSW1	POISSON PROBABILITY.
Q	PROCUREMENT LOT SIZE.
R	REPAIR BATCH SIZE.
REQBUD	REQUIRED BUDGET FOR MSRT GOAL.
RHO	ACTUAL SHIPBOARD STOCK RISK LEVEL.
1-RHO	ACTUAL SHIPBOARD STOCK PROTECTION LEVEL.
RISK	RISK LEVEL USED TO COMPUTE SHIPBOARD STOCK.
RTAT	REPAIR TURN AROUND TIME AT THE DOP FOR A REPAIR BATCH.
SS	SHIPBOARD STOCK LEVEL.
SUM	DUMMY VARIABLE USED TO COMPUTE REQBUD.
SW	STOCK LEVEL IN THE WHOLESALE SYSTEM.
T	RESUPPLY RATE SHIPBOARD.
T1	MEAN SHIPPING TIME FOR A CARCASS FROM THE SHIP TO THE NSC.
T2	SHIPPING TIME FOR A REPAIR BATCH (R) FROM THE NSC TO THE DOP.
T3	SHIPPING TIME FOR A REPAIR BATCH (R) FROM THE DOP OR A PROCUREMENT LOT (Q) FROM THE MANUFACTURE TO THE NSC.
T4	MEAN SHIPPING TIME FOR AN RFI UNIT NOT STOCKED ABOARD SHIP FROM THE NSC TO A SHIP.
T5	TIME REQUIRED FOR THE ICP TO DETERMINE THAT A NKFI UNIT WILL NOT BE RETURNED BY A SHIP.
TAU	PROBABILITY THAT FAILED UNIT WILL BE RETURN TO RFI CONDITION BY REPAIR.
1-TAU	PROBABILITY THAT FAILED UNIT MUST BE REPLACED THROUGH THROUGH PURCHASE.
TOT1	DUMMY VARIABLE USED TO SUM DEMAND TIMES CMSRT FOR ALL ITEMS.
TOT2	DUMMY VARIABLE USED TO SUM TOTAL DEMAND FOR ALL ITEMS.
TT1	MEAN LENGTH OF THE REPAIR CYCLE.
TT2	MEAN LENGTH OF THE PROCUREMENT CYCLE.
U	MEAN WHOLESALE LEVEL RESUPPLY TIME.
WT	COMPUTED WEIGHT USED IN DETERMINING WHICH ITEM TO


```

C      RHO(I) = RISK
C      GO TO 107
C      ***** FOR NON SPCC CALCULATIONS *****
C
C      105 RHO(I) = RISK
C      MSRT = .0579
C      MSRTW(I) = (MSRT - ((1.0 - RHO(I)) * MSRTS)) / RHO(I)
C      MSRTS(I) = MSRTW(I) - T4
C      ***** COMPUTE SHIPBOARD STOCK LEVEL *****
C
C      107 SS(I) = 0.0
C      PROB = EXP(-1.0 * D(I))
C      CDF = 0.0
C      1071 IF(CDF.GE.(1.0 - RHO(I))) GO TO 1072
C      SS(I) = SS(I) + 1.0
C      MULT = D(I) / SS(I)
C      PROB = MULT * PROB
C      GO TO 1071
C      1072 IF(IFLAG.EQ.0) GO TO 1074
C      IF((SS(I).EQ.0.0).AND.((BRF-GT.0.025).AND.
C      *{(IMEC(I).EQ.3).OR.(IMEC(I).EQ.4)})) GO TO 1073
C      GO TO 1074
C      1073 SS(I) = 1.0
C      ***** DETERMINE IF THE ITEM IS A CONSUMABLE *****
C
C      1074 IF(TAU(I).EQ.0.0) T5=0.0
C      ***** COMPUTE TT1, TT2, U, MU *****
C
C      109 IF(TAU(I).GT.0.0) TT1(I) = T1+T2+RTAT+T3+((R-1.0) /
C      *{(2.0*TAU(I)*D(I))}
C      IF(TAU(I).EQ.0.0) TT1(I) = 0.0
C      IF(TAU(I).LT.1.0) TT2(I) = T5+ALT+PLT+T3+((Q-1.0) /
C      *{(2.0*{(0-TAU(I))*D(I)}
C      IF(TAU(I).EQ.1.0) TT2(I) = 0.0
C      U(I) = TAU(I) * TT1(I) + {1.0-TAU(I)} * TT2(I)
C      MU(I) = D(I) * U(I)
C      ***** CHECK IF DEMAND IS EQUAL TO ZERO AND SET GOAL *****
C
C      IF(D(I).EQ.0.0) GO TO 118
C      GOAL = S(I) * MSRTS(I)
C      ***** DETERMINE SMALLEST SW TO SATISFY MSRTS *****

```

```

C
SW(I) = 0.0
PSW1 = EXP(-1.0*MU(I))
CUM = 0.0
MULT = 1.0
110 PSW = MULT*PSW1
FUNC = MU(I) - SW(I) + SW(I)*PSW + (SW(I) - MU(I)) * CUM
IF (FUNC - LE.GOAL) GO TO 115
SW(I) = SW(I) + 1.0
CUM = CUM + PSW
PSW1 = PSW
MULT = MU(I) / SW(I)
GO TO 110

C
****ADJUST SW TO MEET MSRT GOAL *****
C
115 MSRTS(I) = FUNC/D(I)
MSRTW(I) = MSRTS(I) + T4
T = MSRTW(I) * D(I)
PSS = EXP(-1.0*T)
CDF = 0.0
IF (SS(I) - EQ.0.0) GO TO 3010
N = IFIX(SS(I))
DO 3000 J=1,N
  CDF = CDF + PSS
  PSS = (T/FLOAT(J)) * PSS
CONTINUE
3000 FUNC1 = T - SS(I) + SS(I) * PSS + (SS(I) - T) * CDF
3010 CMSRT(I) = FUNC1/D(I)
3020 IF (CMSRT(I) - MSRT) 3025, 3150, 3070
3025 SW(I) = SW(I) - 1.0
  IF (SW(I) - LT.0.0) GO TO 3065
  PSW = EXP(-1.0*MU(I))
  CUM = 0.0
  IF (SW(I) - EQ.0.0) GO TO 3040
  N = IFIX(SW(I))
  DO 3030 J=1,N
    PSW = CUM + PSW
    PSS = (MU(I)/FLOAT(J)) * PSW
    CONTINUE
3030 FUNC = MU(I) - SW(I) + SW(I) * PSW + (SW(I) - MU(I)) * CUM
3040 MSRTS(I) = FUNC/D(I)
  MSRTW(I) = MSRTS(I) + T4
  T = MSRTW(I) * D(I)
  PSS = EXP(-1.0*T)
  CDF = 0.0
  IF (SS(I) - EQ.0.0) GO TO 3060
  N = IFIX(SS(I))

```

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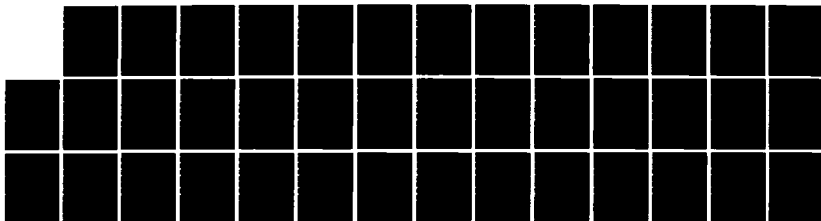
A SYSTEMS APPROACH TO INVENTORY MANAGEMENT OF
REPAIRABLES IN THE NAVY(U) NAVAL POSTGRADUATE SCHOOL
MONTEREY CA C L APPLE MAR 85

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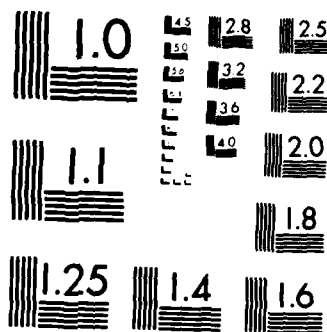
NL



END

FILMED

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

```

DO 3050 J=1,N
  CDF = CDF+PSS
  PSS = (T/FLOAT(J))*PSS
3050 CONTINUE
  FUNC1 = T-SS(I)+SS(I)*PSS+(SS(I)-T)*CDF
  CMSRT(I) = FUNC1/D(I)
  IF(CMSRT(I)-LE-MSRT) GO TO 3020
3065 SW(I) = SW(I)+1.0
  GO TO 3110
3070 SP(I) = SW(I)+1.0
  PSW = EXP(-1.0*MU(I))
  CUM = 0.0
  N = IFIX(SW(I))
DO 3080 J=1,N
  CUM = CUM+PSW
  PSW = (MU(I)/FLOAT(J))*PSW
3080 CONTINUE
  FUNC = MU(I)-SW(I)+SW(I)*PSW+(SW(I)-MU(I))*CUM
  MSRTS(I) = FUNC/D(I)
  MSRTW(I) = MSRTS(I)+T4
  T = MSRTW(I)*D(I)
  PSS = EXP(-1.0*T)
  CDF = 0.0
  IF(SS(I)-EQ-0.0) GO TO 3100
  N = IFIX(SS(I))
DO 3090 J=1,N
  CDF = CDF+PSS
  PSS = (T/FLOAT(J))*PSS
3090 CONTINUE
  FUNC1 = T-SS(I)+SS(I)*PSS+(SS(I)-T)*CDF
  CMSRT(I) = FUNC1/D(I)
  IF(CMSRT(I)-GT-MSRT) GO TO 3070
  GO TO 3150
3110 PSW = EXP(-1.0*MU(I))
  CUM = 0.0
  N = IFIX(SW(I))
DO 3120 J=1,N
  CUM = CUM+PSW
  PSW = (MU(I)/FLOAT(J))*PSW
3120 CONTINUE
  FUNC = MU(I)-SW(I)+SW(I)*PSW+(SW(I)-MU(I))*CUM
  MSRTS(I) = FUNC/D(I)
  MSRTW(I) = MSRTS(I)+T4
  T = MSRTW(I)*D(I)
  PSS = EXP(-1.0*T)
  CDF = 0.0
  IF(SS(I)-EQ-0.0) GO TO 3140
  N = IFIX(SS(I))

```

```

DO 3130 J=1,N
CDF = CDF+PSS
PSS = (T/FLCAT(J)) *PSS
3130 CONTINUE
3140 FUNC1 = T-SS(I)+SS(I) *PSS+(SS(I)-T) *CDF
CMSRT(I) = FUNC1/D(I)
C
C
C ***** COMPUTE ACTUAL SHIPBOARD RISK *****
3150 DEM = MSRTW(I) *D(I)
PROB = EXP(-1.0*DEM)
CDF = 0.0
IF(SS(I).EQ.0.0) GO TO 3170
CDF = PROB
N = IFIX(SS(I))
DO 3160 J=1,N
PROB = PROB*DEM/FLOAT(J)
CDF = CDF+PROB
3160 CONTINUE
3170 RHO(I) = 1.0-CDF
C
C
C ***** WRITE ALL PARAMETERS *****
118 WRITE(6,9060) NIIN(I), COST(I), MSRTS T1,T2,T3,T4
WRITE(6,9061) T5,ALT,MSRT,D(I),+(1.0-TAU(I))
WRITE(6,9062) PLT,R,RTAT
IF(IFLAG.EQ.1) GO TO 1181
WRITE(6,9064) IMEC(I)
GO TO 1182
1181 WRITE(6,9063) BRF,IMEC(I)
1182 WRITE(6,9050) TT1(I),TT2(I),U(I),NU(I),MSRTW(I),MSRTS(I)
IF(D(I).EQ.0.0) GO TO 120
GO TO 140
C
C
C ***** OUTPUT RESULTS *****
120 WRITE(6,9020)
SW(I) = 0.0
CMSRT(I) = 0.0
GO TO 150
140 WRITE(6,9030) +(1.0-RHO(I)),SS(I),SW(I),CMSRT(I)
IF(SW(I).EQ.0.0) WT(I)=0.0
C
C
C ***** REPEAT FOR THE NEXT ITEM *****
150 GO TO 100
C
C
C ***** DETERMINE IF TOTAL COST IS WITHIN *****

```

```

C      ***** BUDGET CCNSTRANT *****
C      190 SUM = 0.0
C      DO 200 I=1,10
C      SUM = SUM+COST(I)*SW(I)
C      200 CONTINUE
C      EXCESS = 0.0
C      REQ BUD = SUM
C      IF(SUM.LE.BUDGET) GO TO 230
C      EXCESS = SUM-BUDGET
C
C      ***** COMPUTE WEIGHTS AND FIND FIRST *****
C      ***** ITEMS TO BE DELETED *****
C
C      DO 210 I=1,10
C      IF(D(I).EQ.0.0).OR.(SW(I).EQ.0.0) GO TO 205
C      WT(I) = COST(I)/(FLOAT(IMEC(I))*CMSRT(I))
C      GO TO 210
C      205 WT(I) = 0.0
C      210 CONTINUE
C      HIGH = 0.0
C      DO 220 I=1,10
C      IF(WT(I).GT.HIGH) HIGH=WT(I)
C      IF(WT(I).EQ.HIGH) J=I
C      220 CONTINUE
C
C      ***** RECOMPUTE NEW MSRT AND WEIGHT FOR ITEM DELETED *****
C
C      SW(J) = SW(J)-1.0
C      EXCESS = EXCESS-COST(J)
C      PSW = EXP(1.0-MU(J))
C      CUM = 0.0
C      IF(SW(J).EQ.0.0) GO TO 4010
C      N = IFIX(SW(J))
C      DO 4000 K=1,N
C      CUM = CUM+PSW
C      PSW = (MU(J)/FLOAT(K))*PSW
C      4000 CONTINUE
C      4010 FUNC = MU(J)-SW(J)+SW(J)*PSW+(SW(J)-MU(J))*CUM
C      MSRTS(J) = FUNC/b(J)
C      MSRTW(J) = MSRTS(J)+T4
C      I = MSRTW(J)*D(J)
C      PSS = EXP(-1.0*I)
C      CDF = 0.0
C      IF(SS(J).EQ.0.0) GO TO 4030
C      N = IFIX(SS(J))
C      DO 4020 K=1,N
C      CDF = CDF+PSS

```


APPENDIX C

DATA INPUT FORMAT

There are three (3) sections of an input file. Data can be input for either SPCC items or non-SPCC items. Examples of both are provided.

SPCC ITEMS

Line 1, Column 1 - enter a '1'

Line 2, Column 1-50 enter the system parameters in the following format:

MSRTS (columns)	T1	T2	T3	T4	T5	RISK	ALT	BUDGET
12345 67890	1	2	3	4	5	12345	67890	1234567890
.001 .50	.300	.25	.05	1.00	.10	2.00	300000.00	

Line 3-12, column 1-60 enter the item parameters in the following format:

NIIN (columns)	x	D	TAU	PLT	R	Q	RTAT	BRF	E	x	COST
123456789 0	1	2	3	4	5	6	7	8	9	0	1234567890
1111111111	4.0	0.99	4.67	1.0	1.0	1.0	1.28	0.0499	3		897.24
2222222222	6.4	0.67	4.95	1.0	1.0	1.0	0.57	0.3321	2		1234.00
3333333333	0.8	0.98	5.30	1.0	1.0	1.0	2.00	0.3841	3		751.00
4444444444	0.4	0.99	4.00	1.0	1.0	1.0	1.07	0.0004	4		160.00
5555555555	2.6	0.99	1.80	1.0	1.0	1.0	0.99	0.0299	3		215.00
6666666666	8.6	0.85	7.14	1.0	1.0	1.0	1.99	0.4002	2		668.66
7777777777	2.7	0.99	3.80	1.0	1.0	1.0	1.21	0.0000	1		14425.00
8888888888	0.5	0.95	3.67	1.0	1.0	1.0	2.00	0.0199	2		1572.00
9999999999	0.3	0.92	4.03	1.0	1.0	1.0	2.00	0.0999	3		1880.00
123456789	0.1	0.93	3.84	1.0	1.0	1.0	0.34	.2799	4		5002.69

Line 1, Column 1 - enter a '0'

Line 2, Column 1-55 enter the system parameters in the following format:

MSRTS T1 T2 T3 T4 T5 RISK ALT BUDGET

(columns) 1 2 3 4 5

12345 67890 12345 67890 12345 67890 12345 67890 1234567890

.001 .50 .300 .25 .05 1.00 .10 2.00 300000.00

Line 3-12, column 1-55 enter the item parameters in the following format:

NIIN x D TAU PLT R Q RTAT xxxx E COST

(columns) 1 2 3 4 5

123456789 0 12345 67890 12345 67890 12345 67890 1234 5 6789012345

111111111 4.0 0.99 4.67 1.0 1.0 1.0 1.28 3 897.24

222222222 6.4 0.67 4.95 1.0 1.0 1.0 0.57 2 1234.00

333333333 0.8 0.98 5.30 1.0 1.0 1.0 2.00 3 751.00

444444444 0.4 0.99 4.00 1.0 1.0 1.0 1.07 4 160.00

555555555 2.6 0.99 1.80 1.0 1.0 1.0 0.99 3 215.00

666666666 8.6 0.85 7.14 1.0 1.0 1.0 1.99 2 668.66

777777777 2.7 0.99 3.80 1.0 1.0 1.0 1.21 1 14425.00

888888888 0.5 0.95 3.67 1.0 1.0 1.0 2.00 2 1572.00

999999999 0.3 0.92 4.03 1.0 1.0 1.0 2.00 3 1880.00

123456789 0.1 0.93 3.84 1.0 1.0 1.0 0.34 4 5002.69

APPENDIX D
RESULTS FOR SPCC ITEMS (UNCONSTRAINED)

NIIN :	111111111
ITEM COST :	897.24
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	4.0000
ATTRITION RATE :	0.0100
PRODUCTION LEADTIME :	4.6700
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	1.2800
BEST REPLACEMENT FACTOR :	0.0499
ITEM MATERIAL ESSENTIALITY CODE :	3
MEAN REPAIR CYCLE TIME :	2.3300
MEAN PROCUREMENT CYCLE TIME :	7.9200
MEAN WHOLESALE RESUPPLY TIME :	2.3859
MEAN QUANTITY IN RESUPPLY :	9.5436
MSRT WHOLESALE GOAL :	1.2005
MSRT RESUPPLY GOAL :	1.1505
SHIP STOCK PROTECTION LEVEL :	0.8865
SHIPBOARD STOCK LEVEL :	7.
COMPUTED WHOLESALE STOCK LEVEL :	5.
ACTUAL MSRT :	0.0528

NIIN :	222222222
ITEM COST :	1234.00
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TC NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	6.4000
ATTRITION RATE :	0.3300
PRODUCTION LEADTIME :	4.9500
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	0.5700
BEST REPLACEMENT FACTOR :	0.3321
ITEM MATERIAL ESSENTIALITY CODE :	2
MEAN REPAIR CYCLE TIME :	1.6200
MEAN PROCUREMENT CYCLE TIME :	8.2000
MEAN WHOLESALE RESUPPLY TIME :	3.7914
MEAN QUANTITY IN RESUPPLY :	24.2649
MSRT WHOLESALE GOAL :	1.2034
MSRT RESUPPLY GOAL :	1.1534
SHIP STOCK PROTECTION LEVEL :	0.8444
SHIPBOARD STOCK LEVEL :	10.
COMPUTED WHOLESALE STOCK LEVEL :	17.
ACTUAL MSRT :	0.0542

NIIN :	333333333
ITEM COST :	751.00
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	0.8000
ATTRITION RATE :	0.0200
PRODUCTION LEADTIME :	5.3000
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	2.0000
BEST REPLACEMENT FACTOR :	0.3841
ITEM MATERIAL ESSENTIALITY CODE :	3
MEAN REPAIR CYCLE TIME :	3.0500
MEAN PROCUREMENT CYCLE TIME :	8.5500
MEAN WHOLESALE RESUPPLY TIME :	3.1600
MEAN QUANTITY IN RESUPPLY :	2.5280
MSRT WHOLESALE GOAL :	0.5826
MSRT RESUPPLY GOAL :	0.5326
SHIP STOCK PROTECTION LEVEL :	0.9881
SHIPBOARD STOCK LEVEL :	2.
COMPUTED WHOLESALE STOCK LEVEL :	3.
ACTUAL MSRT :	0.0168

NIIN :	444444444
ITEM COST :	160.00
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	0.4000
ATTRITION RATE :	0.0100
PRODUCTION LEADTIME :	4.0000
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	1.0700
BEST REPLACEMENT FACTOR :	0.0004
ITEM MATERIAL ESSENTIALITY CODE :	4
MEAN REPAIR CYCLE TIME :	2.1200
MEAN PROCUREMENT CYCLE TIME :	7.2500
MEAN WHOLESALE RESUPPLY TIME :	2.1713
MEAN QUANTITY IN RESUPPLY :	0.8685
MSRT WHOLESALE GOAL :	0.0558
MSRT RESUPPLY GOAL :	0.0058
SHIP STOCK PROTECTION LEVEL :	0.0000
SHIPBOARD STOCK LEVEL :	0.
COMPUTED WHOLESALE STOCK LEVEL :	4.
ACTUAL MSRT :	0.0558

NIIN :	555555555
ITEM COST :	215.00
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DCP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.5500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	2.6000
ATTENTION RATE :	0.0100
PRODUCTION LEADTIME :	1.8000
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	0.9900
BEST REPLACEMENT FACTOR :	0.0299
ITEM MATERIAL ESSENTIALITY CODE :	3
MEAN REPAIR CYCLE TIME :	2.0400
MEAN PROCUREMENT CYCLE TIME :	5.0500
MEAN WHOLESALE RESUPPLY TIME :	2.0701
MEAN QUANTITY IN RESUPPLY :	5.3823
MSRT WHOLESALE GOAL :	1.0162
MSRT RESUPPLY GOAL :	0.9662
SHIP STOCK PROTECTION LEVEL :	0.9478
SHIPOARD STOCK LEVEL :	5.
COMPUTED WHOLESALE STOCK LEVEL :	3.
ACTUAL MSRT :	0.0303

NIIN :	999999999
ITEM : COST :	1880.00
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	0.3000
ATTRITION RATE :	0.0800
PRODUCTION LEADTIME :	4.0300
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	2.0000
ITEM MATERIAL ESSENTIALITY CODE :	3
MEAN REPAIR CYCLE TIME :	3.0500
MEAN PROCUREMENT CYCLE TIME :	7.2800
MEAN WHOLESALE RESUPPLY TIME :	3.3884
MEAN QUANTITY IN RESUPPLY :	1.0165
MSRT WHOLESALE GOAL :	0.4102
MSRT RESUPPLY GOAL :	0.3602
SHIP STOCK PROTECTION LEVEL :	0.9930
SHIPBOARD STOCK LEVEL :	1.
COMPUTED WHOLESALE STOCK LEVEL :	2.
ACTUAL MSRT :	0.0242

NIIN :	888888888
ITEM COST :	1572.00
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	0.5000
ATTRITION RATE :	0.0500
PRODUCTION LEADTIME :	3.6700
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	2.0000
ITEM MATERIAL ESSENTIALITY CODE :	2
MEAN REPAIR CYCLE TIME :	3.0500
MEAN PROCUREMENT CYCLE TIME :	6.9200
MEAN WHOLESALE RESUPPLY TIME :	3.2435
MEAN QUANTITY IN RESUPPLY :	1.6217
MSRT WHOLESALE GOAL :	0.2799
MSRT RESUPPLY GOAL :	0.2299
SHIP STOCK PROTECTION LEVEL :	0.9911
SHIPBOARD STOCK LEVEL :	1.
COMPUTED WHOLESALE STOCK LEVEL :	3.
ACTUAL MSRT :	0.0187

NIIN :	777777777
ITEM COST :	14425.00
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	2.7000
ATTRITION RATE :	0.0100
PRODUCTION LEADTIME :	3.8000
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	1.2100
ITEM MATERIAL ESSENTIALITY CODE :	1
MEAN REPAIR CYCLE TIME :	2.2600
MEAN PROCUREMENT CYCLE TIME :	7.0500
MEAN WHOLESALE RESUPPLY TIME :	2.3079
MEAN QUANTITY IN RESUPPLY :	6.2313
MSRT WHOLESALE GOAL :	0.9506
MSRT RESUPPLY GOAL :	0.9006
SHIP STOCK PROTECTION LEVEL :	0.9534
SHIPBOARD STOCK LEVEL :	5.
COMPUTED WHOLESALE STOCK LEVEL :	4.
ACTUAL MSRT :	0.0257

NIIN :	666666666
ITEM COST :	668.66
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	8.6000
ATTRITION RATE :	0.1500
PRODUCTION LEADTIME :	7.1400
REPAIR BATCH SIZE :	1.
PROCUREMENT LCT SIZE :	1.
REPAIR TURN AROUND TIME :	1.9900
ITEM MATERIAL ESSENTIALITY CODE :	2
MEAN REPAIR CYCLE TIME :	3.0400
MEAN PROCUREMENT CYCLE TIME :	10.3900
MEAN WHOLESALE RESUPPLY TIME :	4.1425
MEAN QUANTITY IN RESUPPLY :	35.6255
MSRT WHOLESALE GOAL :	1.0717
MSRT RESUPPLY GOAL :	1.0217
SHIP STOCK PROTECTION LEVEL :	0.8594
SHIPBOARD STOCK LEVEL :	12.
COMPUTED WHOLESALE STOCK LEVEL :	27.
ACTUAL MSRT :	0.0381

NIIN :	555555555
ITEM : CCST :	215.00
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TC NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	2.6000
ATTRITION RATE :	0.0100
PRODUCTION LEADTIME :	1.8000
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	0.9900
ITEM MATERIAL ESSENTIALITY CODE :	3
MEAN REPAIR CYCLE TIME :	2.0400
MEAN PROCUREMENT CYCLE TIME :	5.0500
MEAN WHOLESALE RESUPPLY TIME :	2.0701
MEAN QUANTITY IN RESUPPLY :	5.3823
MSRT WHOLESALE GOAL :	1.0162
MSRT RESUPPLY GOAL :	0.9662
SHIP STOCK PROTECTION LEVEL :	0.9478
SHIPBOARD STOCK LEVEL :	5.
COMPUTED WHOLESALE STOCK LEVEL :	3.
ACTUAL MSRT :	0.0303

NIIN :	444444444
ITEM CCST :	160.00
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	0.4000
ATTRITION RATE :	0.0100
PRODUCTION LEADTIME :	4.0000
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	1.0700
ITEM MATERIAL ESSENTIALITY CODE :	4
MEAN REPAIR CYCLE TIME :	2.1200
MEAN PROCUREMENT CYCLE TIME :	7.2500
MEAN WHOLESALE RESUPPLY TIME :	2.1713
MEAN QUANTITY IN RESUPPLY :	0.8685
MSRT WHOLESALE GOAL :	0.2302
MSRT RESUPPLY GOAL :	0.1802
SHIP STOCK PROTECTION LEVEL :	0.9960
SHIPOARD STOCK LEVEL :	1.
COMPUTED WHOLESALE STOCK LEVEL :	2.
ACTUAL MSRT :	0.0103

NIIN :	333333333
ITEM COST :	751.00
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	0.8000
ATTRITION RATE :	0.0200
PRODUCTION LEADTIME :	5.3000
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	2.0000
ITEM MATERIAL ESSENTIALITY CODE :	3
MEAN REPAIR CYCLE TIME :	3.0500
MEAN PROCUREMENT CYCLE TIME :	8.5500
MEAN WHOLESALE RESUPPLY TIME :	3.1600
MEAN QUANTITY IN RESUPPLY :	2.5280
MSRT WHOLESALE GOAL :	0.5826
MSRT RESUPPLY GOAL :	0.5326
SHIP STOCK PROTECTION LEVEL :	0.9881
SHIPBOARD STOCK LEVEL :	2.
COMPUTED WHOLESALE STOCK LEVEL :	3.
ACTUAL MSRT :	0.0168

NIIN :	222222222
ITEM COST :	1234.00
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	6.4000
ATTRITION RATE :	0.3300
PRODUCTION LEADTIME :	4.9500
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	0.5700
ITEM MATERIAL ESSENTIALITY CODE :	2
MEAN REPAIR CYCLE TIME :	1.6200
MEAN PROCUREMENT CYCLE TIME :	8.2000
MEAN WHOLESALE RESUPPLY TIME :	3.7914
MEAN QUANTITY IN RESUPPLY :	24.2649
MSRT WHOIESALE GOAL :	1.2034
MSRT RESUPPLY GOAL :	1.1534
SHIP STOCK PROTECTION LEVEL :	0.8444
SHIPBOARD STOCK LEVEL :	10.
COMPUTED WHOLESALE STOCK LEVEL :	17.
ACTUAL MSRT :	0.0542

APPENDIX E

RESULTS FOR NON-SPCC ITEMS (UNCONSTRAINED 90% PROTECTION)

NIIN :	111111111
ITEM COST :	897.24
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	4.0000
ATTRITION RATE :	0.0100
PRODUCTION LEADTIME :	4.6700
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	1.2800
ITEM MATERIAL ESSENTIALITY CODE :	3
MEAN REPAIR CYCLE TIME :	2.3300
MEAN PROCUREMENT CYCLE TIME :	7.9200
MEAN WHOLESALE RESUPPLY TIME :	2.3859
MEAN QUANTITY IN RESUPPLY :	9.5436
MSRT WHOLESALE GOAL :	1.2005
MSRT RESUPPLY GOAL :	1.1505
SHIP STOCK PROTECTION LEVEL :	0.8865
SHIPBOARD STOCK LEVEL :	7.
COMPUTED WHOLESALE STOCK LEVEL :	5.
ACTUAL MSRT :	0.0528

NIIN :	123456789
ITEM COST :	5002.69
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	0.1000
ATTRITION RATE :	0.0700
PRODUCTION LEADTIME :	3.8400
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	0.3400
BEST REPLACEMENT FACTOR :	0.2799
ITEM MATERIAL ESSENTIALITY CODE :	4
MEAN REPAIR CYCLE TIME :	1.3900
MEAN PROCUREMENT CYCLE TIME :	7.0900
MEAN WHOLESALE RESUPPLY TIME :	1.7890
MEAN QUANTITY IN RESUPPLY :	0.1789
MSRT WHOLESALE GOAL :	0.2009
MSRT RESUPPLY GOAL :	0.1509
SHIP STOCK PROTECTION LEVEL :	0.9998
SHIPBOARD STOCK LEVEL :	1.
COMPUTED WHOLESALE STOCK LEVEL :	1.
ACTUAL MSRT :	0.0020

NIIN :	999999999
ITEM COST :	1880.00
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	0.3000
ATTRITION RATE :	0.0800
PRODUCTION LEADTIME :	4.0300
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	2.0000
BEST REPLACEMENT FACTOR :	0.0999
ITEM MATERIAL ESSENTIALITY CODE :	3
MEAN REPAIR CYCLE TIME :	3.0500
MEAN PROCUREMENT CYCLE TIME :	7.2800
MEAN WHOLESALE RESUPPLY TIME :	3.3884
MEAN QUANTITY IN RESUPPLY :	1.0165
MSRT WHOLESALE GOAL :	0.4102
MSRT RESUPPLY GOAL :	0.3602
SHIP STOCK PROTECTION LEVEL :	0.9930
SHIPBOARD STOCK LEVEL :	1.
COMPUTED WHOLESALE STOCK LEVEL :	2.
ACTUAL MSRT :	0.0242

NIIN :	888888888
ITEM : CCST :	1572.00
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	0.5000
ATTRITION RATE :	0.0500
PRODUCTION LEADTIME :	3.6700
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	2.0000
BEST REPLACEMENT FACTOR :	0.0199
ITEM MATERIAL ESSENTIALITY CODE :	2
MEAN REPAIR CYCLE TIME :	3.0500
MEAN PROCUREMENT CYCLE TIME :	6.9200
MEAN WHOLESALE RESUPPLY TIME :	3.2435
MEAN QUANTITY IN RESUPPLY :	1.6217
MSRT WHOLESALE GOAL :	0.0536
MSRT RESUPPLY GOAL :	0.0036
SHIP STOCK PROTECTION LEVEL :	0.0000
SHIPBOARD STOCK LEVEL :	0.
COMPUTED WHOLESALE STOCK LEVEL :	6.
ACTUAL MSRT :	0.0536

NIIN :	777777777
ITEM COST :	14425.00
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TC NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	2.7000
ATTRITION RATE :	0.0100
PRODUCTION LEADTIME :	3.8000
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	1.2100
BEST REPLACEMENT FACTOR :	0.0000
ITEM MATERIAL ESSENTIALITY CODE :	1
MEAN REPAIR CYCLE TIME :	2.2600
MEAN PROCUREMENT CYCLE TIME :	7.0500
MEAN WHOLESALE RESUPPLY TIME :	2.3079
MEAN QUANTITY IN RESUPPLY :	6.2313
MSRT WHOLESALE GOAL :	0.0574
MSRT RESUPPLY GOAL :	0.0074
SHIP STOCK PROTECTION LEVEL :	0.0000
SHIPBOARD STOCK LEVEL :	0.
COMPUTED WHOLESALE STOCK LEVEL :	12.
ACTUAL MSRT :	0.0574

NIIN :	666666666
ITEM CCST :	668.66
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	8.6000
ATTRITION RATE :	0.1500
PRODUCTION LEADTIME :	7.1400
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	1.9900
BEST REPLACEMENT FACTOR :	0.4002
ITEM MATERIAL ESSENTIALITY CODE :	2
MEAN REPAIR CYCLE TIME :	3.0400
MEAN PROCUREMENT CYCLE TIME :	10.3900
MEAN WHOLESALE RESUPPLY TIME :	4.1425
MEAN QUANTITY IN RESUPPLY :	35.6255
MSRT WHOLESALE GOAL :	1.0717
MSRT RESUPPLY GOAL :	1.0217
SHIP STOCK PROTECTION LEVEL :	0.8594
SHIPBOARD STOCK LEVEL :	12.
COMPUTED WHOLESALE STOCK LEVEL :	27.
ACTUAL MSRT :	0.0381

NIIN :	123456789
ITEM COST :	5002.69
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	0.1000
ATTRITION RATE :	0.0700
PRODUCTION LEADTIME :	3.8400
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	0.3400
ITEM MATERIAL ESSENTIALITY CODE :	4
MEAN REPAIR CYCLE TIME :	1.3900
MEAN PROCUREMENT CYCLE TIME :	7.0900
MEAN WHOLESALE RESUPPLY TIME :	1.7890
MEAN QUANTITY IN RESUPPLY :	0.1789
MSRT WHOLESALE GOAL :	0.0504
MSRT RESUPPLY GOAL :	0.0004
SHIP STOCK PROTECTION LEVEL :	0.0000
SHIPBOARD STOCK LEVEL :	0.
COMPUTED WHOLESALE STOCK LEVEL :	3.
ACTUAL MSRT :	0.0504

APPENDIX F

RESULTS FOR NON-SPCC ITEMS (UNCONSTRAINED 65% PROTECTION)

NIIN :	111111111
ITEM CCST :	897.24
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	4.0000
ATTRITION RATE :	0.0100
PRODUCTION LEADTIME :	4.6700
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	1.2800
ITEM MATERIAL ESSENTIALITY CODE :	3
MEAN REPAIR CYCLE TIME :	2.3300
MEAN PROCUREMENT CYCLE TIME :	7.9200
MEAN WHOLESALE RESUPPLY TIME :	2.3859
MEAN QUANTITY IN RESUPPLY :	9.5436
MSRT WHOLESALE GOAL :	0.7625
MSRT RESUPPLY GOAL :	0.7125
SHIP STOCK PROTECTION LEVEL :	0.9109
SHIPBOARD STOCK LEVEL :	5.
COMPUTED WHOLESALE STOCK LEVEL :	7.
ACTUAL MSRT :	0.0360

NIIN :	222222222
ITEM COST :	1234.00
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DCP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	6.4000
ATTRITION RATE :	0.3300
PRODUCTION LEADTIME :	4.9500
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	0.5700
ITEM MATERIAL ESSENTIALITY CODE :	2
MEAN REPAIR CYCLE TIME :	1.6200
MEAN PROCUREMENT CYCLE TIME :	8.2000
MEAN WHOLESALE RESUPPLY TIME :	3.7914
MEAN QUANTITY IN RESUPPLY :	24.2649
MSRT WHOLESALE GOAL :	0.7915
MSRT RESUPPLY GOAL :	0.7415
SHIP STOCK PROTECTION LEVEL :	0.8597
SHIPBOARD STOCK LEVEL :	7.
COMPUTED WHOLESALE STOCK LEVEL :	20.
ACTUAL MSRT :	0.0424

NIIN :	333333333
ITEM COST :	751.00
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	0.8000
ATTRITION RATE :	0.0200
PRODUCTION LEADTIME :	5.3000
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	2.0000
ITEM MATERIAL ESSENTIALITY CODE :	3
MEAN REPAIR CYCLE TIME :	3.0500
MEAN PROCUREMENT CYCLE TIME :	8.5500
MEAN WHOLESALE RESUPPLY TIME :	3.1600
MEAN QUANTITY IN RESUPPLY :	2.5280
MSRT WHOLESALE GOAL :	0.2721
MSRT RESUPPLY GOAL :	0.2221
SHIP STOCK PROTECTION LEVEL :	0.9795
SHIPBOARD STOCK LEVEL :	1.
COMPUTED WHOLESALE STOCK LEVEL :	4.
ACTUAL MSRT :	0.0276

NIIN :	444444444
ITEM COST :	160.00
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	0.4000
ATTRITION RATE :	0.0100
PRODUCTION LEADTIME :	4.0000
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	1.0700
ITEM MATERIAL ESSENTIALITY CODE :	4
MEAN REPAIR CYCLE TIME :	2.1200
MEAN PRCCUREMENT CYCLE TIME :	7.2500
MEAN WHOLESALE RESUPPLY TIME :	2.1713
MEAN QUANTITY IN RESUPPLY :	0.8685
MSRT WHOLESALE GOAL :	0.0558
MSRT RESUPPLY GOAL :	0.0058
SHIP STOCK PROTECTION LEVEL :	0.0000
SHIPBOARD STOCK LEVEL :	0.
COMPUTED WHOLESALE STOCK LEVEL :	4.
ACTUAL MSRT :	0.0558

NIIN :	555555555
ITEM COST :	215.00
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.3500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	2.6000
ATTRITION RATE :	0.0100
PRODUCTION LEADTIME :	1.8000
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	0.9900
ITEM MATERIAL ESSENTIALITY CODE :	3
MEAN REPAIR CYCLE TIME :	2.0400
MEAN PROCUREMENT CYCLE TIME :	5.0500
MEAN WHOLESALE RESUPPLY TIME :	2.0701
MEAN QUANTITY IN RESUPPLY :	5.3823
MSRT WHOLESALE GOAL :	0.4745
MSRT RESUPPLY GOAL :	0.4245
SHIP STOCK PROTECTION LEVEL :	0.9632
SHIPOBOARD STOCK LEVEL :	3.
COMPUTED WHOLESALE STOCK LEVEL :	5.
ACTUAL MSRT :	0.0183

NIIN :	666666666
ITEM CCST :	668.66
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	8.6000
ATTRITION RATE :	0.1500
PRODUCTION LEADTIME :	7.1400
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	1.9900
ITEM MATERIAL ESSENTIALITY CODE :	2
MEAN REPAIR CYCLE TIME :	3.0400
MEAN PROCUREMENT CYCLE TIME :	10.3900
MEAN WHOLESALE RESUPPLY TIME :	4.1425
MEAN QUANTITY IN RESUPPLY :	35.6255
MSRT WHOLESALE GOAL :	0.8619
MSRT RESUPPLY GOAL :	0.8119
SHIP STOCK PROTECTION LEVEL :	0.8696
SHIPBOARD STOCK LEVEL :	10.
COMPUTED WHOLESALE STOCK LEVEL :	29.
ACTUAL MSRT :	0.0326

NIIN :	777777777
ITEM CCST :	14425.00
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	2.7000
ATTRITION RATE :	0.0100
PRODUCTION LEADTIME :	3.8000
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	1.2100
ITEM MATERIAL ESSENTIALITY CODE :	1
MEAN REPAIR CYCLE TIME :	2.2600
MEAN PROCUREMENT CYCLE TIME :	7.0500
MEAN WHOLESALE RESUPPLY TIME :	2.3079
MEAN QUANTITY IN RESUPPLY :	6.2313
MSRT WHOLESALE GOAL :	0.4560
MSRT RESUPPLY GOAL :	0.4060
SHIP STOCK PROTECTION LEVEL :	0.9635
SHIPBOARD STOCK LEVEL :	3.
COMPUTED WHOLESALE STOCK LEVEL :	6.
ACTUAL MSRT :	0.0175

NIIN :	888888888
ITEM COST :	1572.00
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	0.5000
ATTRITION RATE :	0.0500
PRODUCTION LEADTIME :	3.6700
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	2.0000
ITEM MATERIAL ESSENTIALITY CODE :	2
MEAN REPAIR CYCLE TIME :	3.0500
MEAN PROCUREMENT CYCLE TIME :	6.9200
MEAN WHOLESALE RESUPPLY TIME :	3.2435
MEAN QUANTITY IN RESUPPLY :	1.6217
MSRT WHOLESALE GOAL :	0.2799
MSRT RESUPPLY GOAL :	0.2299
SHIP STOCK PROTECTION LEVEL :	0.9911
SHIPBOARD STOCK LEVEL :	1.
COMPUTED WHOLESALE STOCK LEVEL :	3.
ACTUAL MSRT :	0.0187

NIIN :	999999999
ITEM COST :	1880.00
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	0.3000
ATTRITION RATE :	0.0800
PRODUCTION LEADTIME :	4.0300
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	2.0000
ITEM MATERIAL ESSENTIALITY CODE :	3
MEAN REPAIR CYCLE TIME :	3.0500
MEAN PROCUREMENT CYCLE TIME :	7.2800
MEAN WHOLESALE RESUPPLY TIME :	3.3884
MEAN QUANTITY IN RESUPPLY :	1.0165
MSRT WHOLESALE GOAL :	0.0525
MSRT RESUPPLY GOAL :	0.0025
SHIP STOCK PROTECTION LEVEL :	0.0000
SHIPBOARD STOCK LEVEL :	0.
COMPUTED WHOLESALE STOCK LEVEL :	5.
ACTUAL MSRT :	0.0525

NIIN :	123456789
ITEM COST :	5002.69
MSRT SHIP :	0.0010
MEAN SHIPPING TIME TO NSC FROM SHIP :	0.5000
SHIPPING TIME TO DOP FROM NSC :	0.3000
SHIPPING TIME TO NSC FROM DOP OR MANUFACTURE :	0.2500
MEAN SHIPPING TIME TO SHIP FROM NSC :	0.0500
TIME BEFORE ICP DECIDES TO PROCURE :	1.0000
PROCUREMENT ADMIN LEADTIME :	2.0000
DESIRED SYSTEM MSRT :	0.0579
SYSTEM DEMAND RATE :	0.1000
ATTRITION RATE :	0.0700
PRODUCTION LEADTIME :	3.8400
REPAIR BATCH SIZE :	1.
PROCUREMENT LOT SIZE :	1.
REPAIR TURN AROUND TIME :	0.3400
ITEM MATERIAL ESSENTIALITY CODE :	4
MEAN REPAIR CYCLE TIME :	1.3900
MEAN PROCUREMENT CYCLE TIME :	7.0900
MEAN WHOLESALE RESUPPLY TIME :	1.7890
MEAN QUANTITY IN RESUPPLY :	0.1789
MSRT WHOLESALE GOAL :	0.0504
MSRT RESUPPLY GOAL :	0.0004
SHIP STOCK PROTECTION LEVEL :	0.0000
SHIPBOARD STOCK LEVEL :	0.
COMPUTED WHOLESALE STOCK LEVEL :	3.
ACTUAL MSRT :	0.0504

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